A critical analysis of current practices in the treatment of household food waste in Australia - strategic and technical improvements within a Micro Circular Economics (MCE) context

A thesis submitted for the degree of

Doctor of Philosophy

Institute for Sustainability & Innovation
College of Engineering & Science
Victoria University

By

Meris Zheng

March 2020

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Abstract

Food waste (FW), generated from the point of production to the dinner table, represents approximately one third of all the food produced worldwide. It is estimated that more than 95% of household food waste (HFW) goes to landfill and is the major contributor to greenhouse gas (GHG) emissions from such sites, with other environmental impacts such as pollution of groundwater. There are also significant costs involved with the management of FW worldwide. These issues are compounded by increasing urban populations and there is an urgent need to better address the management and disposal/treatment of FW generally - and HFW in particular. In order to achieve this, more research is urgently needed to obtain specific information on the details of HFW management and on the development of appropriate technologies that are consistent with a micro circular economic (MCE) approach. To this end, an extensive review of HFW management and technology worldwide has been conducted.

Together with the above information, in collaboration with three local Councils, research has been undertaken with respect to the Melbourne metropolitan area specifically that involves the design and implementation of a strategy to survey residents across three different well-defined dwelling types, in order to obtain detailed information on their household management and disposal of domestic food waste. Thus, an extensive survey has been designed and conducted that separately targets residents of detached houses, semi-detached/low-rise and high-rise dwellings. This survey has revealed differences in HFW management, attitudes and practices, that that depend on dwelling type - and that also provide important general information and data that has informed the subsequent design, construction and testing of a miniaturized anaerobic-digestion (AD) pilot-plant. This information is of both a qualitative and quantitative nature. For example, it is important to know both the nature and the quantity of the food waste generated as well as residents' attitudes towards disposal and treatment. The designed and constructed pilot plant is meant to serve as a prototype for the on-site treatment of HFW that will produce biogas for domestic consumption. An ultimate goal here is to utilize HFW to supplement a household's gas supply and at the same time remove the necessity of sending HFW to landfill.

Thus the pilot-plant experimental program has collected and analysed replicate temporal data on the effect on biogas (CH_4) production of parameters such as household food waste composition and quantity (as informed by the survey) and texture, the nature of the inoculate, operating conditions such as pH and temperature, oxygen infiltration and fatty acid production - as well as design aspects such as the footprint, the number of tanks and the required control equipment. In terms of biogas yield, a multiple tank set-up has been found to be superior to a single tank set-up and an important aspect has been found to be an appropriate mixing of food waste substrate between AD tanks that results in an increased biogas yield.

In summary, the combination of an extensive targeted survey of HFW management in the Melbourne metropolitan area, coupled with the design and trialling of a potential household pilot plant for the on-site generation of biogas, has yielded valuable information that will eventually result in a commercially viable product.

Declaration

I, Meris Zheng, declare that the PhD thesis entitled "A critical analysis of current practices in the treatment of household food waste in Australia - strategic and technical improvements within a Micro Circular Economics (MCE) context", is no more than 100,000 words in length including citations but tables, figures, appendices, references and footnotes.

This thesis has never been submitted previously in any form or in any other academic qualification. It is my own work expect indicated otherwise.

Meris Zheng

March 2020

Acknowledgements

I would like to express my deep gratitude to all those people who assisted in this project.

Firstly, I especially thank my Principal Supervisor Professor John Orbell, for the theme of this project and for his invaluable guidance and encouragement throughout my research and thesis writing. Without you, this project wouldn't have existed or be finished.

I would also like to thank my Associate Supervisor Professor Robert Fairclough for his supervision throughout the project, especially his assistance in liaising with three different Councils and also in conducting the surveys and in the thesis preparation.

I would also like to thank my Associate Supervisor Dr Dimuth Navaratna for his valuable expertise and advice throughout the project, especially with respect to the anaerobic digestion experiments.

I would like to express my sincere gratitude to Ms Melanie Oke from City of Melbourne and Mr Peter and Ms Hayley Jarvis from the City of Wyndham for their great support and collaboration.

Thanks are also due to the technical staff of Ms Stacey Lloyd, Mr Joseph Pelle, Mr Larruceo Bautista, Mr Miroslav Radev, Mr Donald Ermel and Mr Joseph Angelone, as well as to the research librarian Mr. Cameron Barrie. I am also grateful to all the other staff and fellow academics who have given me invaluable support.

Finally, I extend the greatest appreciation to my dearest friends Mr Mid Pica and Mrs Hellen Pica for their moral and practical support, especially with respect to the design and construction of the pilot plant. Also, I would like to thank my brother Xiaomai and my nephew Peter Li for their support over the duration of my Doctoral research.

Journal publications, conference proceedings and conference presentations relevant to the scope of this thesis.

Refereed Conference Presentation and Proceedings

1. Zheng, M., Orbell, J.D. & Fairclough, R.J. 2017. Household food waste treatment technologies and relevant systems – a systematic review (I). *In:* 5th International Conference on Sustainable Solid Waste Management, June 21-24, 2017, Athens, Greece. (Platform Presentation)

2. Zheng, M., Orbell, J.D. & Fairclough, R.J. 2016. Household food waste treatment technologies and relevant systems – a systematic review (I). In: WWAA National Conference on Energy from Waste, October 25-27, 2016, Sydney, Australia. (Platform Presentation)

3. Zheng, M., Fairclough, R.J. & Orbell, J.D. 2016. Household food waste treatment technologies and relevant systems – a systematic review (II). *In:* 1st International Conference on Food Analysis, November 21-24, 2016, Melbourne, Australia. (Platform Presentation)

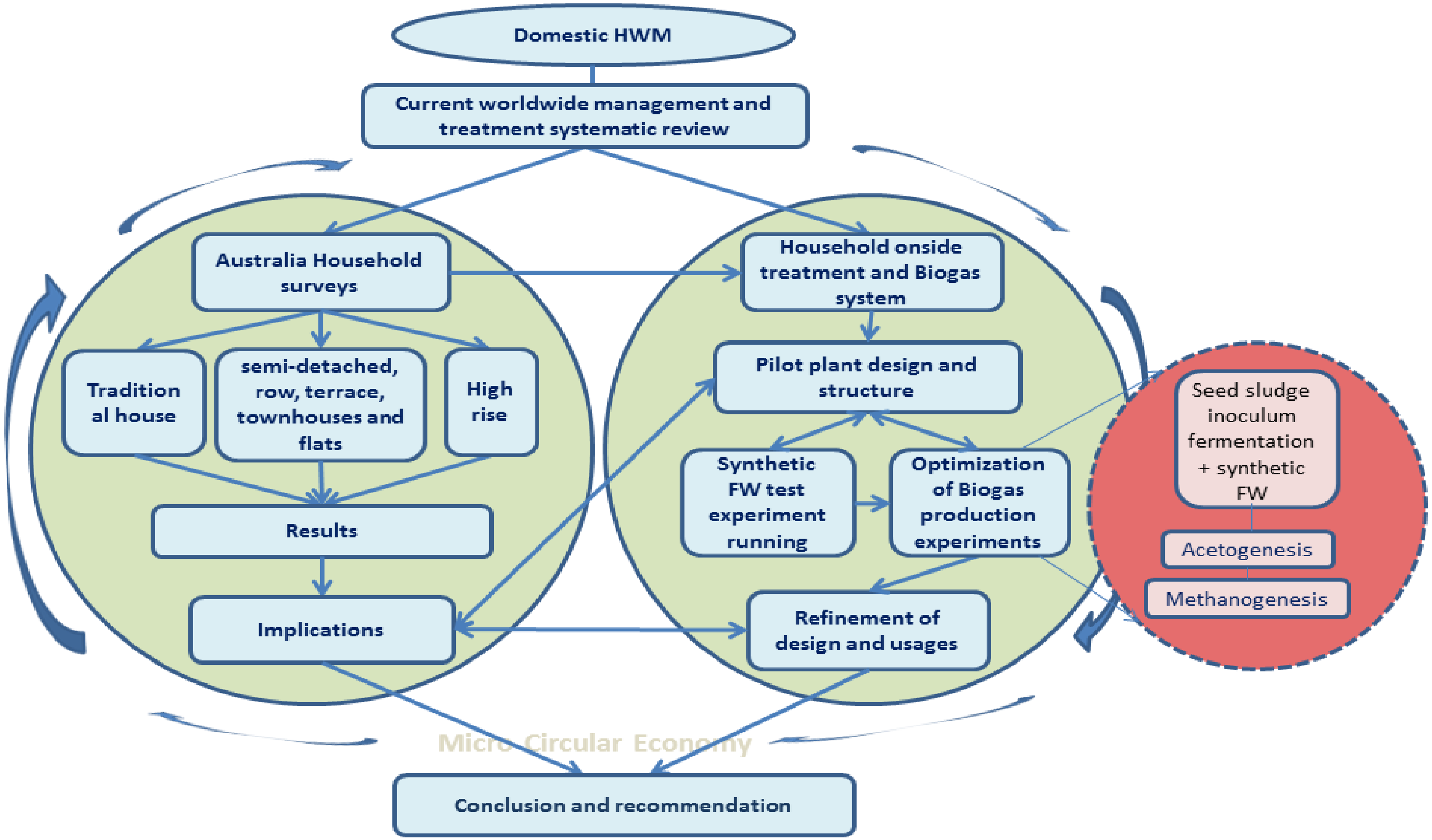
Refereed Journal Articles

1. Zheng, M., Fairclough, R.J. Navaratna, D., Oke, M. & Orbell, J.D. 2020. The design and implementation of a survey to assess the management of household food waste across different types of dwelling. To be submitted to the *Journal of Environmental Management*, in preparation.

2. Zheng, M., Fairclough, R.J. Navaratna, D., Oke, M. & Orbell, J.D. 2020. Differences in the management of household food waste between different dwelling types across the Melbourne Metropolitan area. To be submitted to *Waste Management*, in preparation.

3. Zheng, M., Fairclough, R.J. Navaratna, D., & Orbell, J.D. 2020. The design, construction and testing of a domestic scale household-food-waste anaerobic digester for the production of biogas. To be submitted to *Bioresource Technology*, in preparation.

Conceptual Framework



Micro-Circular-Economic Model for Household Food Waste Management (inside the green wireframe)

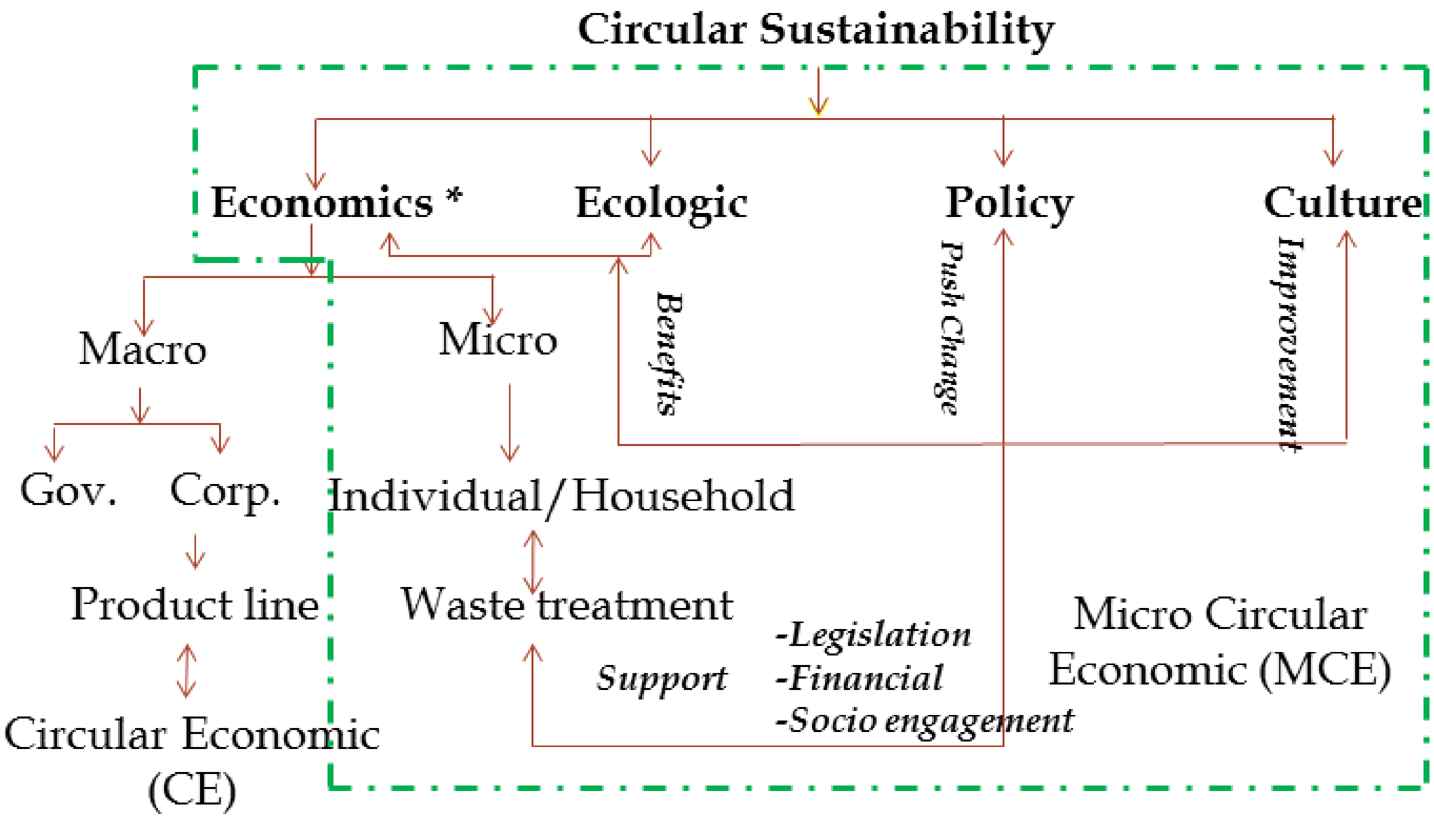


Table of Contents

List of Figures

List of Maps

List of Photos

List of Tables

Abbreviations and Terms

3Rs	Reduce, Reuse and Recycle
5Rs	Refusal, Reduction, Reuse, Recycling and Responsibility
AD	Anaerobic Digestion
Aerobic	A condition in which atmospheric or dissolved oxygen is present in an environment.
Alkalinity	The capacity of water or wastewater to neutralize acids
Anaerobic	A condition in which atmospheric or dissolved oxygen is not present in an environment
BOD5	Biochemical oxygen demand
C	Carbon
Cn	The reference unit with its group number (1, 2 and 3) in the experiments
C/N	Carbon to nitrogen ratio
CBOs	Community based organizations
CC	Commercial composting using Aerobic technology
CE	Circular economic
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand; oxygen reducing capabilities of wastewater
DO	Dissolved oxygen
EPA	Environment Protection Authority
EU	European
FS	Fermentation solution
FW	Food waste including edible waste and unavoidable waste generated in meal prepare, unwanted and left out.
FWP	Food waste processer
GC	Gas chromatography
GDP	Gross domestic product, an indicator of the economic health of a country
GOs	Government organizations
GS	Garden soil

H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulphide
HC	Household composting
GS	Garbage stream: The waste generated daily in household which are not accepted in recycling bin.
HD	High density dwellings include all flats/apartments in a seven or more storey block.
HFW	Food waste generated from households
HFWM	HFW management
HFWT	HFW treatment
HIC	High income countries
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
IT	Incineration treatment
IWM	Integrated waste management
IWWM	Integrated wastewater management
LA	Lactic acid
LCA	Life cycle assessment
LD	Low density dwellings include all free-standing dwellings separated from neighbouring dwellings by a gap of at least half a metre
LF	Land fill
LIC	Low income countries
m^3/day	Cubic meter per day
MBR	Membrane bio-reactor
MCE	Micro circular economic
Mesophilic	Organisms requiring temperature between 25 – 40 ° C to thrive
mg/L	Milligram per liter; measurement of mass concentration
MRFs	Materials recycling facilities
MSW	Municipal solid waste
MSWM	Municipal solid waste management
N_2	Nitrogen

NGOs	Non-governmental organizations
NH_3	Ammonia
NH_3-N	Ammonium nitrogen
NM	Native microorganism
NO_2-N	Nitrite nitrogen
NO_3-N	Nitrate nitrogen
O_2	Oxygen
OCs	Operating conditions
OW	Organic waste includes food waste and garden waste generated from household
pH	Water quality parameter that measures the activity of hydrogen ion
PT	Pilot plant
RS	Recycling stream: As the Australian Waste Database (AWD) has classified, material can be recycled such as glass, plastic and liquid paper board bottles, jars and containers; aluminium and steel cans, aerosols and foil; paper products.
SI	Seed inoculate
T	Temperature, °C
Thermophilic	Organisms requiring temperature between 40 – 80 °C to thrive
TN	Total nitrogen
TOC	Total organic carbon; amount of carbon in an organic compound
TP	Total phosphorus
TSS	Total suspended solids; particles that remain in suspension in wastewater
Turbidity	Cloudiness of water due to suspended solids
USEPA	United States Environment Protection Agency
UASB	Up-flow Anaerobic Sludge Bed wastewater treatment technology
UNEP	United Nations Environment Program
v/v	Volume by volume concentration
VFA	Volatile fatty acid
WHO	World Health Organization
WTE	Waste-to-energy technology, one of the waste management systems

Chapter 1 - Introduction

1.1 Background

Of the food production worldwide, around one third is wasted, which is up to 1.3 billion tonnes per year - prior to 2010 (Food and Agriculture Organization of the United Nations, 2011). Such waste is generated from the point of harvest to the table. This may be further broken down into four broad sectors (European) - manufacturing and processing, wholesale and retail, food service and restaurants, and household (Monier, 2010) - and three sectors in Australia – pre-farm gate, post-farm gate to check-out and check-out to post-consumer (Mason, 2011). The final sector is the same for both Europe and Australia, Figure 1.1. Household consumption is a significant component and is continuing to increase, especially in medium to high income countries (Food and Agriculture Organization of the United Nations, 2011).

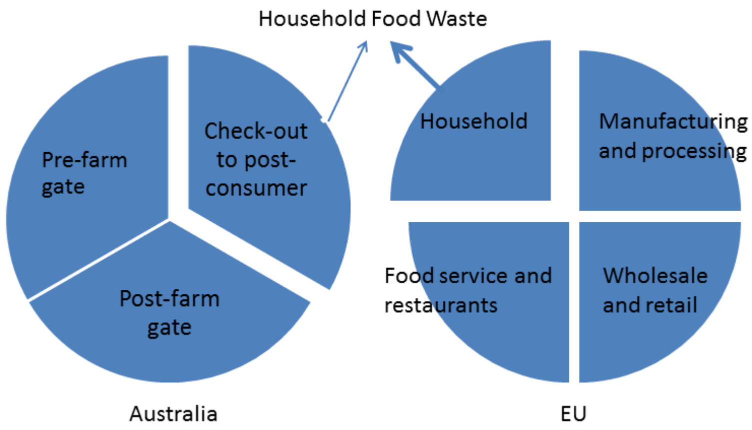


Figure 1.1 Food waste sectors in Australia and the European Union

The first global scientific assessment of food waste published by the International Resource Panel of UNEP (2014) also affirms that household consumption has the most significant impact on the environment. This is especially the case given that the proportion of the world's population living in urban areas will increase from 50% (2008) to 64% in developing countries and to 86% in developed countries by end of 2050 (Department of Economic and Social Affairs, 2013). Thus, the available food production and waste disposal capacity of land per person is becoming increasingly constrained with demand sometimes exceeding supply. In this regard, it should also be noted that FW treatment and disposal may also have adverse environmental impacts with respect to air, land and water. This also includes a loss of biodiversity combined with other resources losses such as energy, water and man-power (Lim and Yalvac, 2010). All of this has tightened up and even restricted landfill practises, especially in high population urban area / developed countries.

Many new technologies that minimise or treat food waste have been developed by the waste management industry, but they also face economic and social issues such as the increasing costs and the necessity of strengthening regulation and compliance. Therefore, sustainability in FWM has become a focal point in an international effort to realign and strengthen the design and deployment of human processes.

There are some concepts, such as the 3Rs - Reuse, Recycle and Recovery, the 5Rs - Refusal, Reduction, Reuse, Recycling and Responsibility in waste management that have been adopted and implemented as part of government policy reform in many parts of the developed world. Reflecting such strategies, actions such as food packaging improvement, food-bank and waste dispose levies have been carried out in order to reach a goal of “Toward Zero Waste”. Meanwhile life cycle assessment (LCA) (Cherubini, 2009, Cherubini, 2011, Messina, 2012, Tonini et al., 2013, Vandermeersch, 2014, Hoefnagels, 2010, Hertwich, 2005) and CE - Circular Economics (Ellen MacArthur Foundation, 2015b) are now common practices in waste management and system design assessment in the food industry (Mirabella, 2014). Also, these actions tend to focus on energy efficiency, resource conversation and GHG emission control from a relatively macro perspectiven（Lim and Yalvac, 2010). The concept of CE would be discussed in more detail in Chapter 2 and shown in diagram of Figure 2.14.

Meanwhile, research on how to minimize FW from household daily life has been conducted in many countries, especially in developed countries. These researchers have focused on promoting sustainable lifestyles around the household and communities such as Efficient Food Use and Food Waste Prevention in Households through Increased Awareness (EUPHORIA) (Lim and Yalvac, 2010) etc.

In addition, energy demand is projected to increase by up to 50% by 2025 (Kader et al., 2015), although, on a brighter note, renewable energy such as solar energy, wind power, geothermal and wave power generation etc. are undergoing rapid development and implementation.

With respect to consumers attitudes to FW, Exodus Market Research (2007) showed that ~75% of 2,939 surveyed households across thirteen local administrative districts in the UK stated that they had not been influenced by food packaging and that FW generated from households was "unavoidable and out of their control". The HFW contain up to 80% - 95% water. It is also high in protein, starch, fat, other organic matter. Also, there is the perception that within and during a storage period, HFW would contain pathogens, pathogenic microorganisms, would rot, be smelly and would attracting flies, cockroaches and rats that are harmful to humans and environment.

All of the above factors highlight the urgency of improving household food waste management (HFWM) community awareness and the development of useful treatment technologies in urban areas, especially with high population densities.

1.2 Research aims

Improving the sustainability and effective utilization of environmental resources is a multi-faceted challenge that crosses many boundaries including engineering, chemistry, ecology, economics, politics and culture. Each of these dimensions is shaped by influences and behaviour at an individual, community, local, state and national government level. The key research questions to be addressed for this project are:

What constitutes sustainable HFW management and which are the most applicable practices that might be applied in the Australian context? This research will provide insights and possible solutions to this question by examining current issues and opportunities at both a system-wide and individual consumer level.

More specifically the study has been designed to explore the following aspects:

- What current HFWM systems have been successfully implemented internationally and within Australia?
- Which aspects of international best practice may be applicable in Australia?

- What are the current issues holding back the development of household food waste management (HFWM) in Australia with specific reference to the Victorian situation? How can we overcome those barriers?

- Where are the opportunities for accelerating the cost-effective adoption of processes that can improve HFWM in Victoria?

- How do consumers deal with bio waste in their own households and what is their view of present Council bio-waste treatment systems? What are the major issues in relation to waste processing and practice innovation and how can barriers to adopting novel solutions be addressed and within an MCE framework?

- How may specific technological developments, such as gas generation from HFW, can be designed and incorporated into current best practice.

Some general aims are listed below:

1. To conduct and publish an exhaustive review of the management and treatment of HFW worldwide.

2. Within the above context, to review and investigate current practices in the household food waste treatment (HFWT) in Australia.

3. In consultation with the Councils and the Metropolitan Waste Recovery Board, to identify areas for strategic and technical development within a Micro Circular Economics (MCE) framework.

4. To access and analyses the current HFW management auditing reports of three selected cities - City of Wyndham, City of Yarra and City of Melbourne, representing the outer, inner and central cit y respectively.

5. In the context of the above audit analyses and discussions with the councils, to develop and conduct relevant surveys of stakeholders including council workers, contractors and the general public in order to define important new areas for development.

6. Develop a deeper understanding of the dependencies between environmental, technological, economic and societal factors as they relate to HFWT and, more

specifically, to identify the opportunities and impediments to the development of an integrated MCE approach to HFWT.

7. As part of a specific technical development, to conduct laboratory-based experiments to examine the potential for the generation of useful quantities of gas from HFW and to explore how such technology could be incorporated into existing practices.

8. To select one or more such areas for future more detailed scrutiny and research.

1.3 References

Bernstad, A & la Cour Jansen, J 2012, 'Review of comparative LCAs of food waste management systems – Current status and potential improvements', *Waste Management*, vol. 32, no. 12, pp. 2439-55.

Bernstad, A, Wenzel, H & la Cour Jansen, J 2016, 'Identification of decisive factors for greenhouse gas emissions in comparative lifecycle assessments of food waste management–An analytical review', *Journal of Cleaner Production*, vol.;[0

Bhander, GS, Christensen, TH & Hauschild, MZ 2010, 'EASEWASTE—life cycle modeling capabilities for waste management technologies', *The International Journal of Life Cycle Assessment*, vol. 15, no. 4, pp. 403-16.

Boulding, KE 1966, 'the Economics of the Coming Spaceship Earth'.

Carre, A, Crossin, E & Clune, S 2015, *LCA of kerbside recycling in Victoria*, 1.3, RMIT University.

Cherubini, FB, S; Ulgiati, S 2009, 'Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration', *Energy*, vol. 34, no. 12, pp. 2116-23.

Cherubini, FS, A. 2011, 'Life cycle assessment of bioenergy systems: State of the art and future challenges', *Bioresource Technology*, vol. 102, no. 2, pp. 437-51.

Department of Economic and Social Affairs 2013, *World Economic and Social Survey 2013: Sustainable Development Challenges*, United Nations, New York.

Ellen MacArthur Foundation 2015, *The circular model brief history and schools of thought*.

Exodus Market Research 2007, *We don't waste food! A householder survey*, <www.wrap.org.uk>.

Food and Agriculture Organization of the United Nations 2011, *Global food losses and food waste - extent, causes and prevention*, Rome, <http://www.fao.org/docrep/014/mb060e/mb060e.pdf>.

Hertwich, EG 2005, 'Life Cycle Approaches to Sustainable Consumption: A Critical Review', *Environmental Science and Technology*, vol. 39, no. 13, pp. 4673-84.

Hoefnagels, RS, Edward; Faaij, André 2010, 'Greenhouse gas footprints of different biofuel production systems', *Renewable and Sustainable Energy Reviews*, vol. 14, no. 7, pp. 1661-94.

Kader, F, Baky, AH, Khan, MNH & Chowdhury, HA 2015, 'Production of Biogas by Anaerobic Digestion of Food Waste and Process Simulation', *American Journal of Mechanical Engineering,*, vol. 3, no. 3, p. 5.

Korse, M 2015, 'A Business Case Model to Make Sustainable Investment Decisions - Adding Circular Economy to Asset Management', Master thesis, University of Twente.

Laurent, A, Bakas, I, Clavreul, J, Bernstad, A, Niero, M, Gentil, E & Hauschild, MZC, Thomas H 2014, 'Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives', *Waste Management*, vol. 34, no. 3, pp. 573-88.

Lim, V & Yalvac, F 2010, 'Household food waste prevention how to design and evaluate technological interventions?', p. 3.

Mason, LB, T; Fyfe, J; Smith, T; Cordell, D 2011, *National food waste assessment-final report*, Institute for Sustainable Futures, UTS.

Messina, A 2012, *Sustainability measurement handbook*, Delhi : University Publications; 1st ed.

Mirabella, NC, Valentina; Sala, Serenella 2014, 'Current options for the valorization of food manufacturing waste: a review', *Journal of Cleaner Production*, vol. 65, pp. 28-41.

Monier, VM, S; Escalon, V; O'Connor, Clementine; Anderson, Gina; Montoux, Hortense; Reisinger, Hubert; Dolley, Phil; Ogilvie, Steve; Morton, Gareth 2010, *Bio food waste - final report*, Euopean Commission.

Tonini, D, Martinez-Sanchez, V & Astrup, T 2013, 'Material Resources, Energy, and Nutrient Recovery from Waste: Are Waste Refineries the Solution for the Future?', *Environmental Science & Technology*, vol. 47, no. 15, pp. 8962-9.

UNEP 2014, *Assessing Global Land Use: balancing consumption with sustainable supply*.

Vandermeersch, TA, R. A. F.; Ragaert, P.; Dewulf, J. 2014, 'Environmental sustainability assessment of food waste valorization options', *Resources, Conservation and Recycling*, vol. 87, no. 0, pp. 57-64.

Chapter 2: Household Food Waste Treatment Technologies - A Systematic Review

2.1 Introduction

Household consumption and associated waste management issues have a significant environmental impact (UNEP, 2014). For HFW only, it makes up 30 - 68% of the total municipal solid waste (MSW) in developed countries and 20 - 45% in developing countries as indicated in Chapter 1. Figure 2.1 give more detail data with different regions. In this regard, it is predicted that the world's urban population will increase rapidly from 50% (in 2008) to 64.1% in developing countries and 85.9% in developed countries by end of 2050 (Department of Economic and Social Affairs of the United Nations Secretariat, 2013). This increase in urban population will mean even greater and more complex sustainability challenges in the future in relation to household waste.

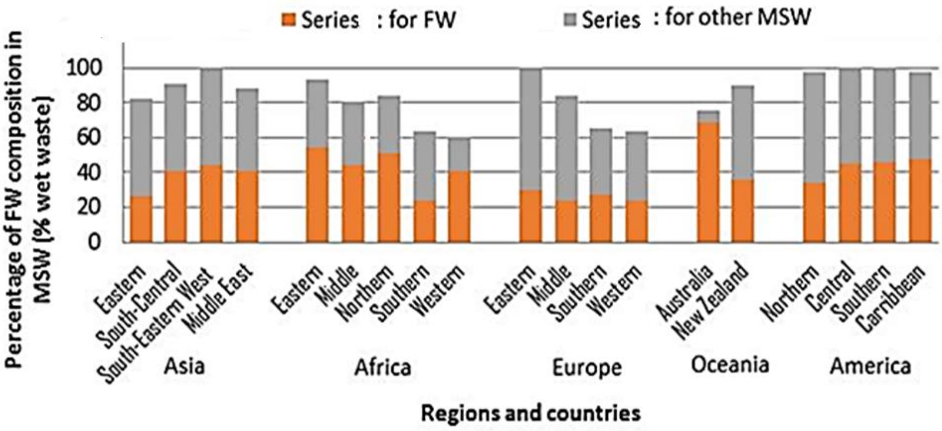


Figure 2.1 The percentage of different waste types in municipal solid waste in different regions and countries (reproduced from Pham (2015)).

Over the last 23 years the International Union for the Conservation for Nature and Natural Resources (IUCN) finally developed and released a plan for sustainable development (Thiele, 2013) in order to realign and strengthen the design and deployment of human activities internationally. The concept of "Toward Zero Waste" has been adopted and implemented by some governments worldwide. Thus strategies such as 3R, 5R and CE are now common practices in waste management, especially in the food industry (Mirabella, 2014). However, all these activities are on a macro scale requiring considerable resources including land, manpower and energy, which have significant implications for the environment. Palmer (2004) has said: “The money that is wasted on garbage collection and dumping is money that is spent to destroy our planet”. Thiele (2013) stated that the concept of sustainability always provides room for improvement and must be based on balancing ecological health, economic welfare and social empowerment.

Sustainability is not just simply minimising negative impacts but is also concerned with maximising positive impacts on our environment. It may also be argued that management or development will not be sustainable without an economic benefit. Indeed, since 2012 the physical environment has been linked with economics as “asset flows” in the System of Environmental-Economic Accounting – Central Framework (United Nations, 2014).

Due to the wide range of substances in FW and its lower calorific value and methane generation potential, a dedicated treatment system(s) for this waste is required. However, any development and use of household FW treatment and management systems will be affected by a wide range of factors including a country’s GDP, transparency index, educational levels, religion and culture, policy planning, availability of appropriate technology, waste collection, characterisation and separation techniques, the market for recycled material and people's awareness of sustainability (Rousta et al., 2015). For this reason, innovation and development of FW technology and management systems, especially those that can be used at the community or household level, is extremely challenging.

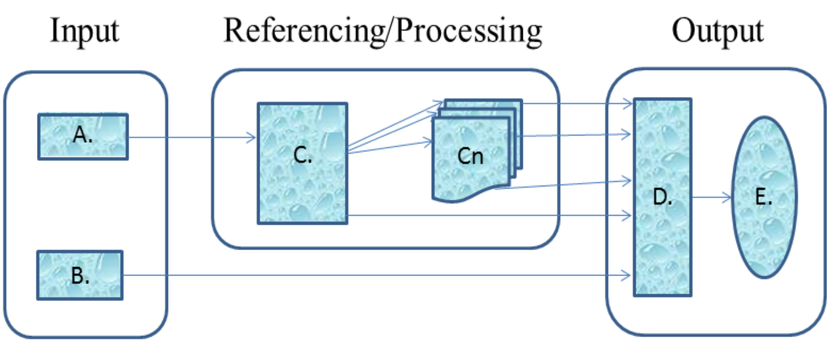
Through reviewing current international research papers and reports, this project aims to identify and compare the advantages and disadvantages of current technologies and relevant operating systems for the management of Household Food Waste (HFW) worldwide. The papers/reports of published that have been selected place an emphasis on Life Cycle Assessment (LCA) as a tool for comparing various food waste management methods. An attempt is also made to relate this information to our concept of “Micro Circular Economics” (MCE) – an offshoot of Circular Economics (CE) (Ellen MacArthur Foundation, 2015a). Thus, this project will attempt to relate new technological developments to innovative management systems in order to ensure that the management of HFW will benefit both the environment and the economy.

2.2 Methodology

2.2.1 Literature search strategy

This review uses standard desktop searching tools including Google Scholar, Web of Science and Science Direct, as listed in Table 2.1. Citation collections will also be included in the review using the Snowballing method (Mason, 2011). Information from public databases, post 2009 (Laurent et al., 2014b), will also be accessed from government and organisational websites. Figure 2.2 shows the process that will be used to undertake this literature review. The United Nations (UN), the European Unit Commission (EUC) and available Government databases will also be used in searching for relevant data of selected research papers.

The number of publications and references contained therein that cover waste treatment technologies is obviously very large. In order to establish a practical system for reviewing such literature, selection criteria need to be formulated. In this paper, there will be a focus on Life Cycle Assessment (LCA) and the biological treatment of waste using anaerobic digestion, whilst for other technologies, assessments will be based on this.



A.: Scholarly articles selected from database listed in Table 1;
B.: Information from UN, EUC and available governments database;
C.: Reference; Cn.: processing of reference;
D.: Evaluation and comparison of relevant information; and
E.: Results and conclusion.

Figure 2.2 A schematic of the literature review process.

Table 2.1 List of academic databases and search engines

Name	Discipline(s)	Description	Provider(s)
EBSCO Information Services	Multidisciplinary	Online research service which includes 375 full-text databases and over 600,000 e-books	EBSCO Publishing (https://www.ebsco.com)
Elsevier including • Science Direct, • Scopus, and • Elsevier Research Intelligence	Multidisciplinary	Elsevier is a world-leading information and analytics provider. It covers 2,500 journals and contains over 13 million documents. It publishes over 400,000 articles with over 900 million downloads annually. It also the world's largest peer-reviewed research literature database which contains over 20,500 titles from more than 5,000 international publishers.	Elsevier Publisher (https://www.elsevier.com)
Google Scholar	Multidisciplinary	Includes the most peer-reviewed online academic journals and books, conference papers, theses and dissertations, preprints, abstracts, technical reports, and other scholarly literature, including court opinions and patents. Covers approximately 80-90% of all articles published in English.	Google (https://scholar.google.com)
SpringerLink	Multidisciplinary	SpringerLink is a global publishing company that publishes books, e-books and peer-reviewed journals in science, technical and medical (STM) publishing. It also hosts a number of scientific databases.	Springer (http://www.springer.com/gp/)
Web of Science	Multidisciplinary	The Web of Science Core Collection covers over 12,000 of the highest impact journals worldwide.	Thomson Reuters (http://thomsonreuters.com/en.html)
WorldWide Science	Multidisciplinary	A one-stop database searching engine-a 'global science gateway' which comprises multi-government organisations. It "provides real-time searching and translation of globally dispersed multilingual scientific literature".	The United States Department of Energy, Office of Scientific and Technical Information serves as the operating agent for WorldWideScience (http://worldwidescience.org/)

2.2.2 Selection of criteria for comparison of references

Over recent years, LCA has progressed from focusing, not only on environmental impacts, but also on costings and on the impacts of socio-economic considerations. These developments have resulted in LCA becoming a comprehensive sustainability analysis tool (Korse, 2015). Turner et al. (2016) have also demonstrated that LCA can give valuable information for decisions on waste management systems. Meanwhile the principles of Circular Economics (CE) ("cradle-to-cradle") have been also put into practice in more and more industries, especially following the influential publication of "The Economics of the Coming Spaceship Earth" (Boulding, 1966). All of these different concepts have made the waste management options even more varied and complex. Therefore, in this research the comparison reference selection is basis on the journey article of LCA of FW treatment internationally.

Before comparison, the different FW management options and the definition of scope and system boundaries is essential to avoiding uncertainty.

2.2.2.1 Life cycle assessment (LCA)

LCA, as assessed by ISO 14044 (2006), has become an important measuring tool for monitoring sustainable waste management. The ISO 14040 and 14044:2006 Standards Handbooks have provided the basic framework for specific applications, along with international reference guides. Based on the ISO Standards Handbooks a number of models have been developed during the last two decades (Table 2.2). Each model has its own focus point and drawbacks.

As a science-based methodology, LCA has been used since the 1970s to study the environmental interventions and potential impacts throughout a life cycle from raw material acquisition to production, use and disposal (i.e. from cradle-to-grave). It is intended to quantify all environmental impacts in order to assist decision making and to choose appropriate waste management systems for different countries, cities or local communities (Abeliotis et al., 2012, Cherubini, 2009, Cherubini, 2011, Hertwich, 2005, Hoefnagels, 2010, Messina, 2012, Tonini et al., 2013, Vandermeersch, 2014, Güereca et al., 2006).

2.2.2.2 LCA FW management system boundaries and measurement (function) units

Defining household food waste (HFW):

FW may be defined as "food losses occurring at the end of the food chain (retail and final consumption)" (Food and Agriculture Organization of the United Nations, 2011). In this research, HFW includes uneaten food and food scraps generated during household meals.

The system boundary and inventory:

The concept of boundary conditions is an important factor when comparing technology options for HFW management (Bernstad et al., 2016b) due to the complexity of HFW management. This not only influences the individual but also the whole of society. The process of HFW management starts from the treating of the primary waste to producing secondary waste or recyclable products - up to the final point. All involve energy, manpower and natural resources input and will be contributing impacts or emissions to the environment both directly and indirectly (Bhander et al., 2010), Figure 2.3. Therefore, defining the boundary of the system is extremely important in waste treatment research in particular.

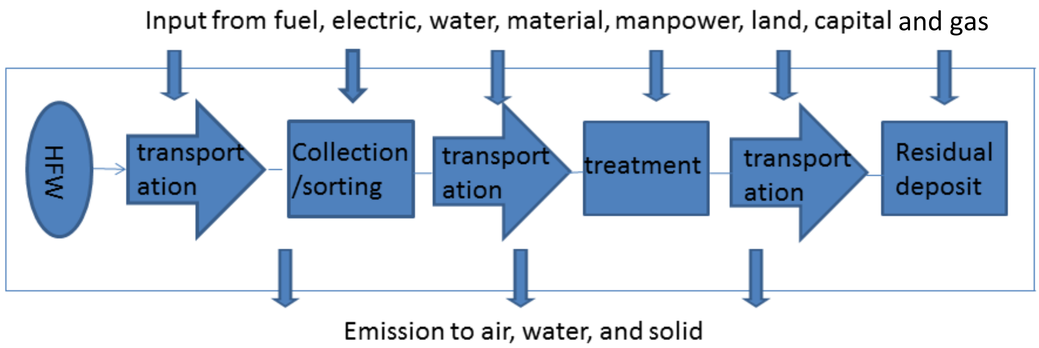


Figure 2.3 Boundary of HFW Management with upstream input and downstream outflows

In this research, the boundary conditions are set from the household kitchen to the final disposal point of the FW. Within the boundary, the management system can be divided into three main sections indicated in Figure 2.4; I, II and III. I represents the source of HFW from a household's kitchen, then involves internal to external storage (the on-site disposal of 'informal routes'- decentralized and road side garbage bin of "formal disposal methods"- centralized). II represents the first level of treatment of HFW, which includes the collection, sorting/separating, transportation, operations by council services or contractors using trucks and transit facilities (if using centralized treatment). For III, the FW may go in three directions including (i) burning in waste-to-energy facilities - but it is likely to consume more energy than it generates due to the high water-content (ii) it may be mixed with other green waste to go to a composting site, and (iii) landfill. For the latter two methods both will generate methane gas that contribute to global warming.

Comparing the two management flow lines, the centralized HFW management system will involve more processing and is more difficult to implement and maintain in an efficient way than the decentralized.

Function unit*:*

The function unit is established to assess the relative impacts of environmental and economic factors (Carre et al., 2015). The unitary function unit is the foundation by which comparisons can be made using different management systems. In this research the management of FW is expressed in kg. All treatments, emissions, resources, material flow calculations will be based on this unit.

Indicator selection:

HFW management comparisons will embrace environmental, economic, and social considerations.

Environmental impact: The indicators for environmental impact comparisons will focus on three categories and nine sub-categories that are commonly used in LCA. These indicators are commonly used as basic assessment tools which are considered to be important for the local and the wider community.

- Non-toxic impacts which include: GHG emissions, acidification potential, eutrophication potential;
- Toxicity impacts which include: human toxicity potential, eco-system toxicity potential - including terrestrial and aquatic environments,
- Resource usage, including energy, water and land.

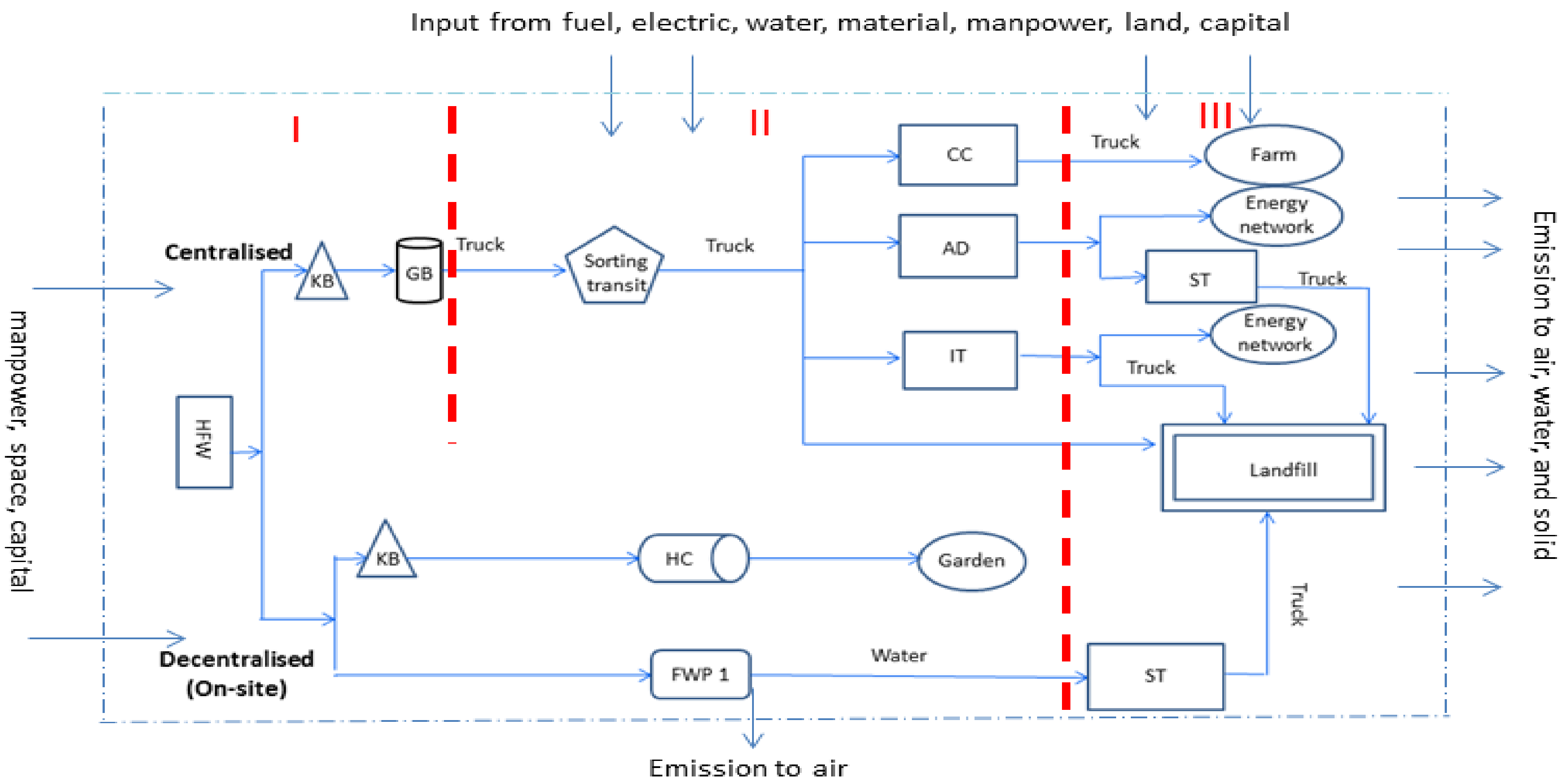


Figure 2.4 Road map for the HFW management system with upstream input and downstream outflow. I = Section I; II = Section II; and III = Section III. AD: Anaerobic digestion plant; CC: Commercial composting plant; FWP: food waste processer; GB: garbage bin; HC: home composting; HFW: household food waste; IT: Incineration treatment plant; KB: kitchen bin; and ST: sewage treatment plant

Table 2.2 Life Cycle Assessment Models, application scenarios and critique

Model name	Framework	Mainly applies to:	References	Critique
SimaPro software	Based on input-output materials flow	Analysing environmental burden, for assessment of alternatives and environmental performance of MSW-MS	Zaman (2010) Bovea et al. (2010) (Spain) Song et al. (2013) (China)	Limited time frame
WISARD	Not available	Vague, for selecting the best MSW-MS	Feo and Malvano (2009) (Italy)	Does not support the inclusion of other waste types and does not provide economic evaluation or geographical coverage.
Umberto 5.5 software	Not available	Vague, for a future MSW-MS	Pires et al. (2011) (Portuguese):	
WRATE modeling	Not available	Vague, for the assessment of different energy recovery strategies	Tunesi (2011) (England):	
EASEWASTE	Most commonly used model. Constructed from individual elements and includes and the quantitative relations between these elements. Describes the unit processes of the waste management system, such as waste collection by truck or an incineration technology.	Evaluation of the environmental performance of the various elements of existing or proposed solid waste management systems. Land assessment, material sorting and recycling, bottom and fly ash handling, material and energy utilization. Mainly developed for waste types from households and small commercial business units. Tracks the impact of individual technologies, waste sources, material fractions, or individual substances.	Slagstad and Brattebø (2012) (Norway) Bernstad and la Cour Jansen (2012a) (Sweden) Merrild et al. (2012) (Denmark) Bhander et al. (2010)	Does not support the inclusion of other waste types and does not provide economic evaluation or geographical coverage.
ORWARE	Rarely used		Eriksson et al. (2005) et al (Sweden)	

Economic and social impacts: These are assessed separately under the following headings:

- Sociological: here only discuss the reliability of energy supply; ensuring the safety of people, facilities, regions and places with an emphasis on a long-term sustainability with regular monitoring.
- Economic: this involves maintaining viable production, distribution and consumption of goods and services, short and long-term profitability and availability of feedstock, being receptive towards technological advances, cost of production and transport and distribution costs and benefits. This is all influenced by production costs.

Another important consideration is the fact that data shows that occupational accidents in the waste management industry are relatively common and are at a level that, on the basis of epidemiological studies, is much higher than national averages for other occupations (Giusti, 2009).

2.2.3 Systematic analysis tool

Qualitative interpretation: The management system of FW covers the period from the collection from the household to waste disposal. Because it is common practice to include FW in the MSW this review will include FW as part of MSW.

This review will also take into account economic, cultural and geographical factors together with new technological advances in the discussion of the management systems (Dellinger, 2013, Rousta et al., 2015).

A study undertaken by the Food and Agriculture Organization of the United Nations (FAO) (Food and Agriculture Organization of the United Nations, 2011) reported that the amount of FW generated in developed countries is 10 times more than that from developing countries. Australia, as a developed country, will be compared with similar countries such as those of the EU, the United States of America and Canada, Japan and the two highest-population developing counties, China and India. (Oxford Dictionaries, n.d., Department of Economic and Social Affairs of the United Nations Secretariat, 2013).

2.3 Critical analysis of the current literature

2.3.1 Search results

Keyword combinations used for this review included the key words of "household food waste", or "household kitchen waste" or "MSW" and "treatment" or "management", "life cycle assessment" and "comparative" or "comparison". The search included all sources within the title, abstract, keywords of journals or books and SU Subject terms and AB Abstracts. The time-frame covered 2006 - 2016 and the review was restricted to full text and peer reviewed articles in the English language. A search fof Google Scholar resulted in 781 articles with 776, 4 and 1 published in academic journals, dissertations/theses and conference materials, respectively. 519 of them included information on LCA, environmental assessment and 222 included articles on MSW treatments such as composting, anaerobic digestion, landfill and incineration – respectively, 74, 53, 60, 130, and 138. A search of ScienceDirect, resulted in a total of 29 articles with 8 results related to LCA or economical assessment; 7 on anaerobic treatment and 2 on household attitudes. Searches using the key words of "household food waste" and "treatment technology" resulted in 50 relevant articles. 28 articles have also been found from other sources as indicted in Table 1 and from Pergamon Press and the American Chemical Society. All the results on HFW treatment can be divided into two categories: centralized and decentralized encompassing the four technologies of biological, thermal, landfill and food waste processing.

2.3.2 HFW treatment systems

HFW has well-defined constituents and has: a high moisture content that can be up to 80% - 95%, high salt content, protein, starch, fat and other organic matter. It is also rich in nitrogen, phosphorus, potassium, calcium and other trace elements. Other substances present in HFW may include complex chemicals, pathogenic microorganisms, flies, cockroaches and vermin. Because of such potentially harmful characteristics, HFW must be disposed of on a daily basis in many countries or cities, especially where there are high temperatures, such as some cities in south China and some countries in south Asia. For example, the amount of HFW generated from a city of 200,000 households would potentially generate 200,000 kg of FW assuming each household disposed of about 1 kg of food waste per day. High amounts of HFW lead to a heavy workload and expense for councils in order to cover collection, processing and disposal. In order to reduce the cost to councils, HFW has traditionally been mixed with other MSW prior to landfill disposal. This method of collecting waste has had a detrimental impact on our environment.

Following increasing concern by communities on the impact of the HFW on the environment, most governments of the world have started to change or adopt new food waste treatment (FWT) systems (Chapter 3 would discussed these in more detail). However, this is influenced by government policy and finances, politics, long-term planning and geographical considerations. Other considerations include land availability, the size and population density of the city, the degree of urbanization, available water resources, income and lifestyles, cultural and eating habits, education levels and community environmental awareness.

As alluded to previously, there are two system models for household FW disposal from primary processing points (Figure 2.3): i.e. centralised treatment systems and on-site/decentralised treatment systems. The technologies for these are reiterated here as: biological technologies, mechanical biological treatment, thermal technologies and landfill technologies (WSN Environmental Solution, 2005).

2.3.2.1 Centralized treatment system:

Centralised treatment is the major model for urban residential areas. It is mostly run by local governments and/or contractors. The centralised system includes collection, separation and treatment processes.

Collection and sorting: HFW starts from a household’s kitchen. There are two common type of collection depending on local regulations. One is source-separation by the household and the other involves collection of the mixed waste from the kerbside.

For source-separation, the FW is stored in according to either a wet or a dry method. The common wet method simply stores the FW inside the kitchen bin of the house prior to collection. The dry method that is used in some countries involves putting the FW in bench-top containers, firstly to dry off the liquid and then it is sealed them into a biodegradable bag or paper bag. The food scraps are then stored in a garden organics bin for fortnightly or even three-weekly collection. In summer, the FW may also be stored in the fridge in order to reduce odious until a green organics collection (ZWSA, 2010).

The most common practice is mixing FW with other household waste and putting it into a MSW bin outside the house to wait for council collection once a week/fortnight. With both of these methods, the FW can begin its own biological processes from the time it is placed in the storage container. Notably, during storage, a large change can occur with the FW such as losses of carbon and nutrients (Bernstad, 2012).

Bernstad and la Cour Jansen (2012b) suggested that on-site dewatering of FW using paper bags before collection would have less impact on global warming when compared with the four current systems. This view was made in relation to the input of waste for AD treatment in Sweden. Rigamonti et al. (2009) commented that when the source-separated collection rate achieved 60% the MSW treatment has less impact on the environment.

FW processing: It is common practice to mix FW with other MSW prior to it being sent to a commercial garbage depot site or to a transfer station. The garbage stream is then transferred to up to four different treatment facilities depending on a countries' or region's regulations. The four treatments are commercial composting, anaerobic digestion, incinerate and landfill.

2.3.2.2 Decentralizing / On-site treatment system:

With on-site treatment, the FW is treated internally within households without being transferred to the council's garbage collection system. There are two common practices in developed countries: home composting and the treatment of FW using a food waste processor under the kitchen sink. Home composting is normally used by residents who live in a house with a certain size of backyard. For Household FW composting, a number of treatments are used including container composting, sheet composting, trench composting or vermicomposting[1] . The HFW is normally kept in the kitchen bin for latter transfer to a compost bin. In order to avoid anaerobic reactions and to prevent insects and animals being attracted to the decomposing FW, there are some rules that need to be followed, such as no meat in the FW, and the FW should be mixed with garden trimmings (Nair and Okamitsu, 2010).

[1] https://en.wikipedia.org/wiki/Compost

2.3.3 FW treatment technologies

2.3.3.1 Biological treatment

Anaerobic digestion (AD)

AD is a commonly used biological treatment for FW alongside composting – aerobic facilities. AD is a process which can generate biogas for electricity generation. Within the AD process, organic material is broken down by microorganisms in the absence of oxygen to produce biogas. It includes the stages of: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Figure 2.5 and 2.6).

FW is an ideal substrate for AD as it contains 80 - 97% of volatile solids (VS) of the total solids (TS), 70 - 90% water by weight and a carbon to nitrogen ratio (C/N) of 14.7–36.4, (Zhang et al., 2014, Zhang et al., 2007). Four processes are involved in the commercial-scale process of AD: biodegradable waste separation, removal of contaminants, homogenization pre-treatment, biogas generation by anaerobic digestion and residue post-treatment (Kosovska, 2006). There is also number of small-scale AD reactor units which have been mainly installed in rural areas worldwide because the long reacting time of around 40 days for larger size reactor unit.

The digestion and main stage of AD requires an appropriate pH, temperature, nutrient levels and C:N ratio, which are important for the efficient operation of the process. Currently, 5 main AD technologies are used (Tampio et al., 2014, Zhang et al., 2014).

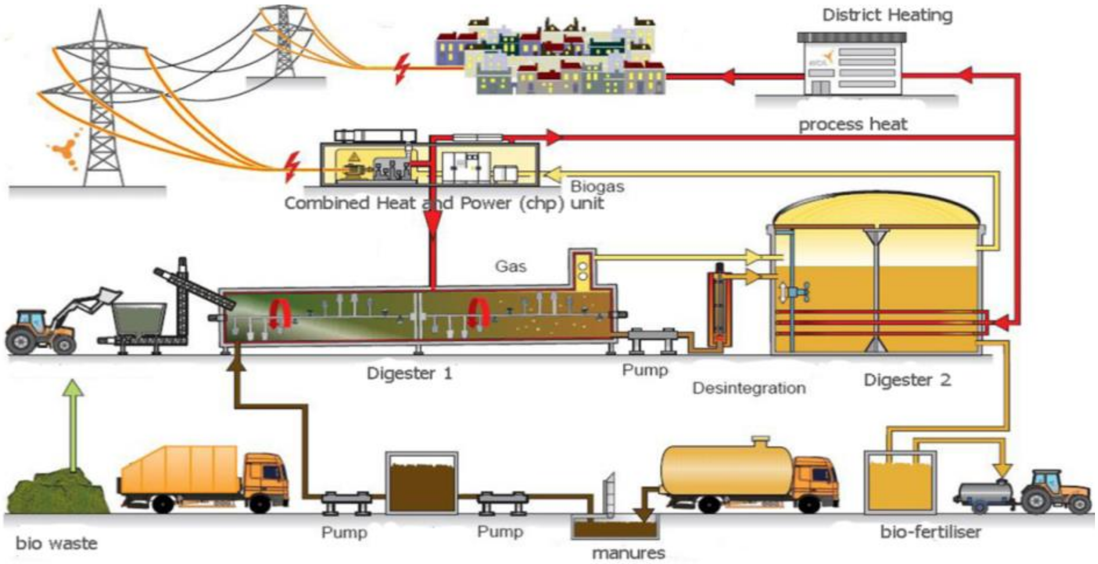


Figure 2. 5 Commercial anaerobic digestion plants[2]

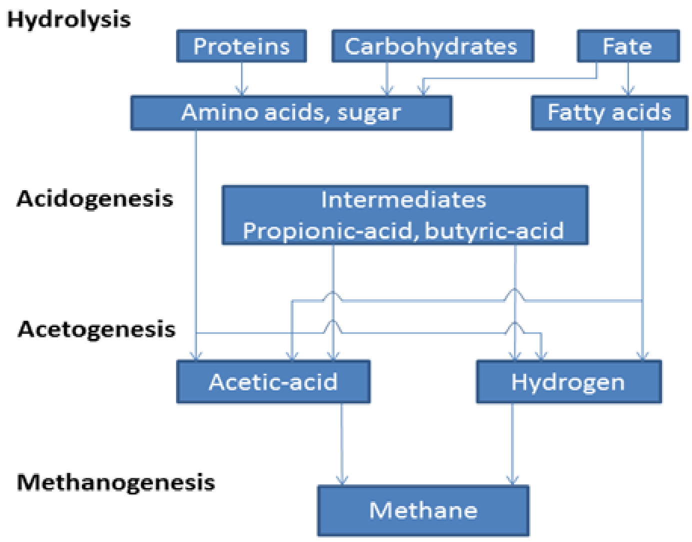


Figure 2.6 Anaerobic digestion processes (reproduce from Tsang (2013))

Given the potential advantages of AD for waste treatment with respect to energy, environmental and economic considerations, in comparison with to other treatments (Ariunbaatar, 2014), the AD process has attracted numerous research studies. Especially in treatment of FW has become increasingly popular. However for the developing of smaller-scale anaerobic digester that can be installed on-site still face

[2] http://www.fabbiogas.eu/en/home/about-biogas/

great challenges due to a number of technical factors including reaction times and methane gas yield (Zhang et al., 2016).

Aerobic digestion - Composting

Composting has a very long history as an important method for the biological treatment of FW. In this process, FW and organic waste are degraded by microorganisms such as bacteria and fungi in the presence of oxygen, at a 60-70% moisture content and a carbon to nitrogen ratio (C/N) of 30/1 for a period more than 6 weeks (Tweib et al., 2012, Recycled Organics Unit, 2007b). The major elements involved in the composting process are shown in Figure 2.7. However, there are some organic wastes such as meat, fish and cooked food that cannot be composted (Diener et al., 1993).

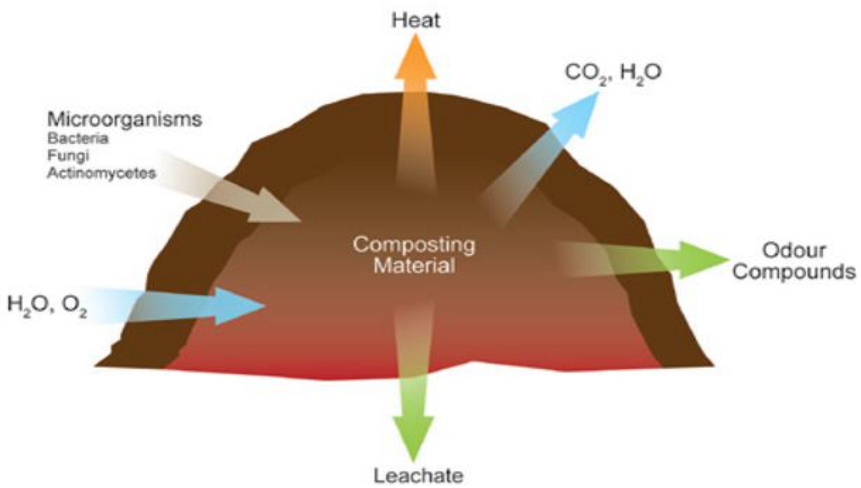


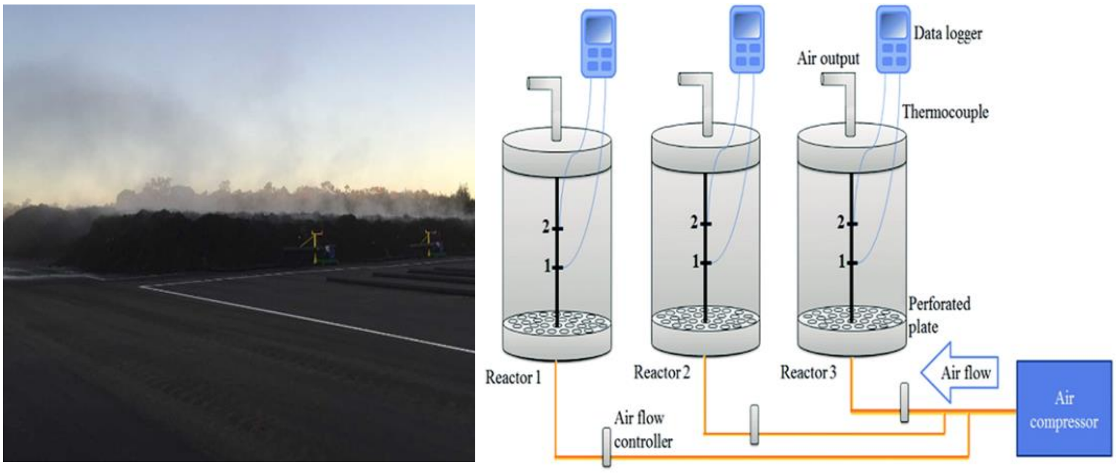
Figure 2.7 Composting major elements flow direction [3]

The important elements of oxygen, water, carbon and nitrogen are required for optimum composting: oxygen for the decomposition process, water for optimum growth microbial oxidation, carbon for energy and nitrogen for growth of organisms[1]. In order to start the

[3] https://www.google.com.au/search?q=composting&biw=1206&bih

process, FW must be mixed with other bulking material such as plant trimmings, wood chips (Zafar, 2014) and other dried crude plant fibers such as straw and sawdust etc. in certain ratios and even with the addition of inoculates (Xi, 2005, Li, 2015, Abdullah et al., 2011, Ohtaki, 1998). The quality of the compost is dependent on moisture, pH, EC, organic matter (OM) and extractable P, as well as other nutrients and factors such as the size and stability of the particles and the pathogen levels (Tweib et al., 2012). A C/N value below 12 indicates the 'maturity' of the compost.

There are a number of different industrial composting systems which include aerated static pile composting (Figure 2.8 a.), high fiber composting, in-vessel composting (Figure 2.8 b.), tunnel composting, windrow composting, vermicomposting and microbial composting. Also, there are other small scale of composting processes such as the composting bin which have been used for decentralization treatment for residents and the community.



a. b.

Figure 2.8 Composting facilities: a. pile composting; b. in-vessel composting process drawing

2.3.3.2 Thermal treatment

Incineration treatment (IT)

Incineration treatment is one of three thermal technologies that require high temperatures to alter the chemical structure of waste. Thermal treatment of waste can result in a 90% reduction of the original volume and 70-80% of its mass (Zhang, 2014, Lombardi, 2015).

Waste to Energy (WtE) or Energy from Waste (EfW) plants are now commonly used and use the heat produced from the thermal plant heat for electricity production. In some countries which have less land available, incineration has becomes one of most important MSW treatment methods alongside other thermal conversion technologies, such as gasification and pyrolysis (Astrup et al., 2014).

The high moisture content of up to 80% in FW has led to the need to pre-treat and co-combust with coal in order to ensure that the incineration is operating efficiently (Lombardi, 2015). However, even under optimum conditions, the energy efficiency is only 18 - 34%, depending on the size and technology used. The final ashes are sent to landfill. Figure 2.9 shows the complexity of an IT plant.

Within the incineration process the composition of waste in moisture, ash and combustibles must be lower than 50%, 60% and over 25% respectively as showed as the shaded area in Figure 2.10. In addition, the temperature of gaseous combusting must be over 850 ºC and up to 1,400 ºC for a minimal of two seconds depending on the type of waste (Lombardi, 2015). Therefore, the operation must be under a number of strict controlled conditions to ensure the wastes have been completely burned off and minimal quantities of hazardous chemicals are released into the environment.

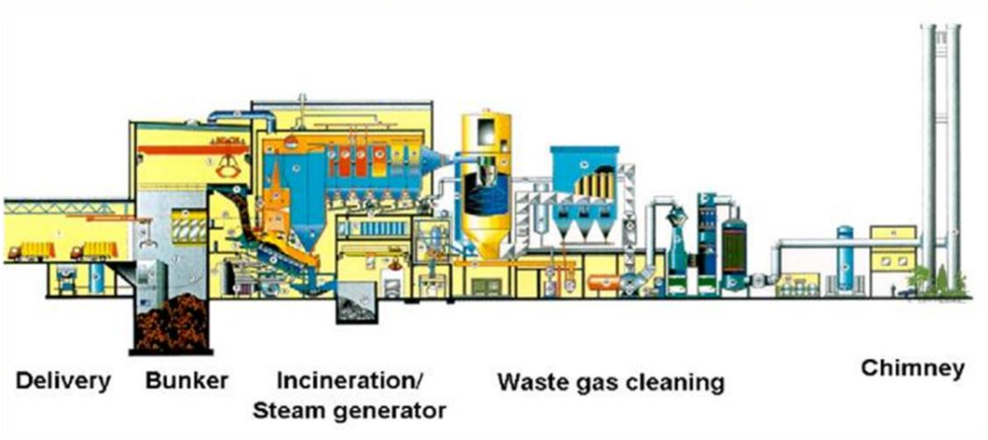


Figure 2.9 Main steps of waste incineration process

[4] https://www.google.com.au/search?q=composting&biw=1206&bih

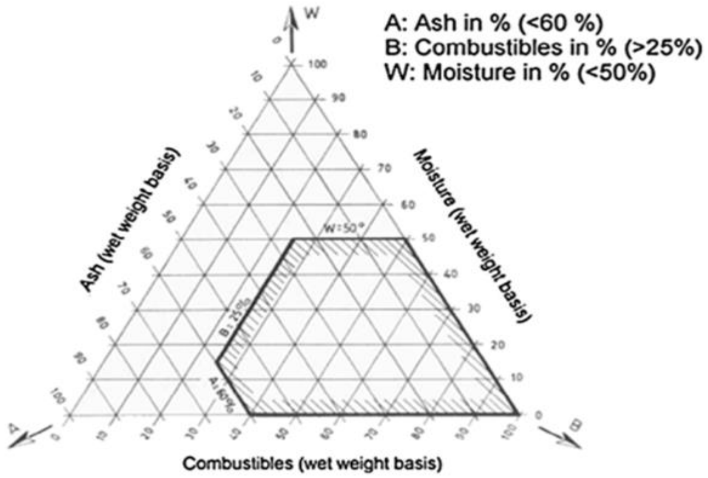


Figure 2.10 The self-combustibility (shaded area) of MSW during incineration ((Lombardi, 2015)

Gasification /Pyrolysis (G/P)

Gasification and Pyrolysis are both complex physical and chemical processes. They are more complex and costly to operate and maintain than IT (Lombardi, 2015).

Gasification generally takes place at temperatures higher than 600 ^{o}C in the presence of oxygen-enriched air or pure oxygen. The net efficiency is about 23 - 31% which varies with plant size (Viganò et al., 2010) .

Pyrolysis takes place at about 400 - 800 ^{o}C in a rotary kiln, which is indirectly heated by a portion of the flue gases (approximately 20%) from syngas combustion. This process produces steam which drives a steam turbine generator for power generation. The gross electric conversion efficiency is about 16%. It is only suitable for specific waste flows such as cooking oil (Lombardi, 2015).

There are also other newly developed pyrolytic technologies such as Torrefaction which is a milder but slower process with lower temperatures of 250 - 350^{o}C and 20 - 30 min retention time compared to previous technologies. Carbonization operates at a temperature of 500 - 600^{o}C and 10 min retention time, compared to the high pyrolysis process which operates at temperatures over 800 ^{o}C and 5 min retention time (Vakalis et al., 2016). The carbonization and pyrolysis processes have been used in treating HFW after a pretreatment process which reduces the water content from 80%

80% to 10% (Figure 2.9) [4].

2.3.3.3 Landfill treatment (LT)

Landfill is the oldest treatment method of FWT, apart from animal feed. However, traditional landfill sites have caused serious public health issues in the past and have had detrimental environment impacts including air pollution, methane emissions, water pollution, leachate and litter. Research from the World Bank showed that each tonne of organic waste produced 300 - 1000 kg of CO_2 when sent to landfill (Zaman and Reynolds, 2015).

Following increasing public health and environmental concerns, modern landfills have been designed and built into the shape of a huge complex in-ground vessels in order to reduce adverse environmental impacts (e.g. Figure 2.11) (Transpacific, 2014).

Currently, there are six common technologies that are used for landfill treatment: open dump, conventional with flares, conventional with energy recovery, standard bioreactor, flushing bioreactor and semi-aerobic landfills (Manfredi and Christensen, 2009). The first one has been banned in most countries due to the impacts on the environment and toxicity concerns, while some of the other technologies are still in use worldwide. Those technologies have made landfill become complex and costly. Figure 10 shows the typical layout of a modern Sanitary Landfill. Emissions from landfill gas and leachate from “high-tech landfills” have a long-term impact on humans and eco-systems. Available data shows that 50% of carbon and 99% of heavy metals from household waste will remain in the landfill site at the end of a 100 year time horizon and the landfill gas and leachate collection system will have significantly reduced in efficiency (Manfredi and Christensen, 2009).

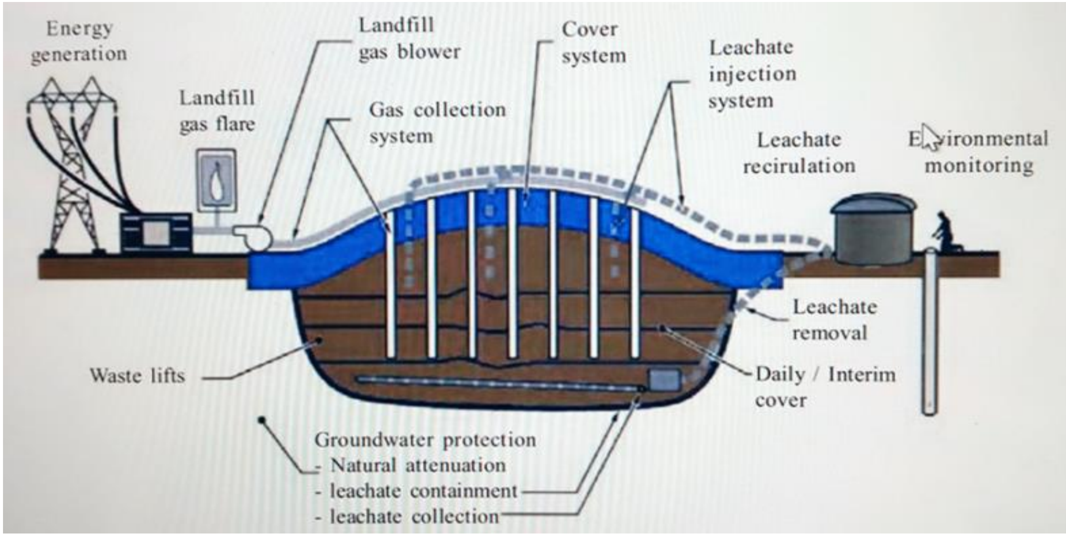


Figure 2.11 Sanitary Landfill model drawing (Transpacific, 2014)

2.3.3.4 The food waste processor (FWP)

The FWP is now a common practice prior to the treatment of HFW. The FWP was first introduced in the USA and was usually installed under the kitchen sink (Iacovidou, 2012). There are currently two types of food waste processors. The first type uses an electrical driven mixer to macerate food waste, in combination with water, to flush down the homogenate into sewer system. The second type is an advance on the first by dehydrating the macerated FW to produce either a compost material for potting mix or to be transferred into a MSW bin (Figure 2.12).

(a) (b) (c)

Figure 2.12 FWP draw out: a) collected in tank for community, b) under kitchen sink flue to sewage system, c) de-water processor

Since 2000, the use of a FWP located under kitchen sinks has been promoted extensively in the USA and some European countries. However, since that time, more data has been made available, indicating that FWP use had led to an increase in the BOD from 20 to 65%, suspended solids from 40 to 90% and fats, oils and grease from 70 to 150%, in septic tanks (USEPA, 2000). The extensive use of FWP also had a major effect on water consumption, sewerage systems and wastewater (Iacovidou, 2012). Australia generally has a water shortage (Lundie and Peters, 2005) so all efforts to reduce water consumption is an important consideration in the processing of FW.

Food waste processors have been available for several decades - in the USA and more recently in most industrialized countries. Food processors have proved to be a very convenient way for residents to treat HFW especially for those who are living in apartments and small units within urban areas.

2.3.4 Analysis and interpretation

To compare different FW treatment technologies, this review focused on the research articles which assessed a comparison between AD and other technologies such as composting, thermal, landfill and FWP. Some 19 studies which covered over 169 scenarios were selected and compared. Parameters that were included in this comparison included different methodologies, functional units, system boundary settings, resources input and product output and mass flow and waste composition. However, given the differences in geographical, temporal scope, the technologies used, time horizons and other uncertainties, it has been very difficult to compare different studies (Astrup et al., 2014, Bernstad et al., 2015, Bernstad et al., 2016b). Therefore, for this review, the comparison was made in digital form using grades. Five grades from 1 to 5 were used to represent the combination of environmental impacts, the economic and social benefits. They are: 1 = not acceptable, 2 = partly acceptable, 3 = neural, 4 = good and 5 = excellent. The final combination result will calculate using the formula (1):

Final combination grade = ($\sum_{n=i} Ni$) / n (1)

N: grade of each assessment result; n: number of scenarios; i: number of references

Table 2.1 List of references and the results of assessments comparison with difference technologies

Reference	**Geography**	**Waste type**	**Scenarios number**	**Combination result with different technologies**				
				AD	**CC**	**HC**	**IT**	**LF**
Ahamed et al. (2016)	Asian Singapore	FW	3	5			1	
Bernstad (2012)	Worldwide	30-40 % HFW	52	5	3	3	4	1
Bernstad et al. (2016a)	EU Sweden	HFW	3	3				
Bernstad and la Cour Jansen (2011)	EU	FW	5	5	2		4	
Bernstad and la Cour Jansen (2012a)	EU Sweden	FW	25	5	2		3	1
(Chi et al., 2015)	China	MSW	4	5	4		3	2
Chiu et al. (2015)	Asian Macau	HFW+ Sewage	5	5			1	
Dou (2015)	China	FW	qualitative	5	3		3	1
Hill (2010)	EU Denmark	HFW	2	4			2	
Khoo et al. (2010)	Asian Singapore	FW	4	5	1	2	1	
Koroneos and Nanaki (2012)	EU Greece	FW + paper	6	5				1
Levis et al. (2010)	USA and Canada	FW	3	5	3			
Manfredi et al. (2015)	EU	HFW	25	5	2		3	1
Nakakubo et al. (2012)	Asian Japan	HFW + Sewage	12	5			1	
Righi et al. (2013)	EU Italy	Organic MSW	4	4	3			1
Takata et al. (2013)	Japan	FW	6	5	3			
Turner et al. (2016)	UK	HFW	4	1			2	4
Zhao and Deng (2014)	Asian HK	HFW	6	5	3	4		1
Zschokke et al. (2012)	USA	FW		5	4			1

Table 2.3 lists the results for each reference. The combined grades are 4.2, 2.8, 3, 2.3, and 1.4, respectively, for AD, CC, HC, IT, and LF. These results show that the AD treatment system (4.2) is the favoured option compared to the other systems of CC, HC, IT and LF; with the LF treatment system (1.4) being the worst option. These results also agree with the results undertaken by Bernstad and la Cour Jansen (2012a) who reviewed 25 studies of 105 scenarios done prior to 2009.

2.4 Discussion

2.4.1 Environment impact and comparison

Table 2.4 lists the main environmental impacts within MSW management facilities with respect to specific factors (Giusti, 2009, Manfredi et al., 2015). Such impacts can be divided into three main categories, namely; non-toxic impacts, toxic impacts and resource usage; and nine sub-categories which have been descripted previously.

Table 2.2 Main environmental impact of municipal solid waste management (reproduced from (Giusti, 2009, Manfredi et al., 2015))

	Water	**Air**	**Soil**	**Climate**
Anaerobic Digestion	Minor impact	CO_2, N_2O	Minor impact	Neural emissions
Composting	Leachate	CO_2, CH_4, VOCs, dust, odour, bioaerosols	Minor impact	emissions of greenhouse gases*
Incineration	Fall-out of atmospheric pollutants	SO_2, NO_x, N_2O, HCl, HF, CO, CO_2, dioxins, furans, PAHs, VOCs, dour, noise	Fly ash, slags	Greenhouse gases*
Landfill	Leachate (heavy metals, synthetic organic compounds)	CO_2, CH_4, odour, noise, VOCs	Heavy metals, synthetic organic compounds	Worst option for greenhouse gases emission*
Recycling Waste transportation	Wastewater Spills	Dust, noise CO_2, SO_2, NO_x, dust, odour, noise, spills	Landfilling of residues Spills	Minor emissions Significant contribution of CO_2

AD does not just recover energy through biogas but also utilizes the residual as carbon storage. When the FW from high energy crops is used for AD on an industrial scale, it can result a net avoidance of GHG-emissions several times higher than for most other treatment technologies (Bernstad et al., 2015). Bernstad and la Cour Jansen (2012a) stated that, even with an unclear framework, using different methodologies and within various systems boundaries as documented in the 105 studies reviewed, there were clearly environmental impacts across the different treatment technologies (Figure 2.13). Based on the existing literature, we can see that AD technology has the minimum impact in Global Warming Potential (GWP) compared to incineration treatment (IT), landfill (LF) and composting. This result is similar to the study by Turner et al. (2016). Zschokke et al. (2012) also showed that even from the perspective of the total Eco-indicator 99, AD has the minimum value compared to CC, IT and LF - being 38%, 42%, 51% and 100%, respectively. Furthermore, Zhao and Deng (2014) supported the concept that landfill of FW has the highest impact on global warming - even with energy recovery. Composting of FW had the highest impact on acidification and nutrient enrichment. Zhao et al. (2010) also showed that replacing landfill by incineration would not have improved the impact on the environment. However, a combination treatment of digestion and composting can reduce water born human toxicity, acidification, nutrient enrichment and global warming.

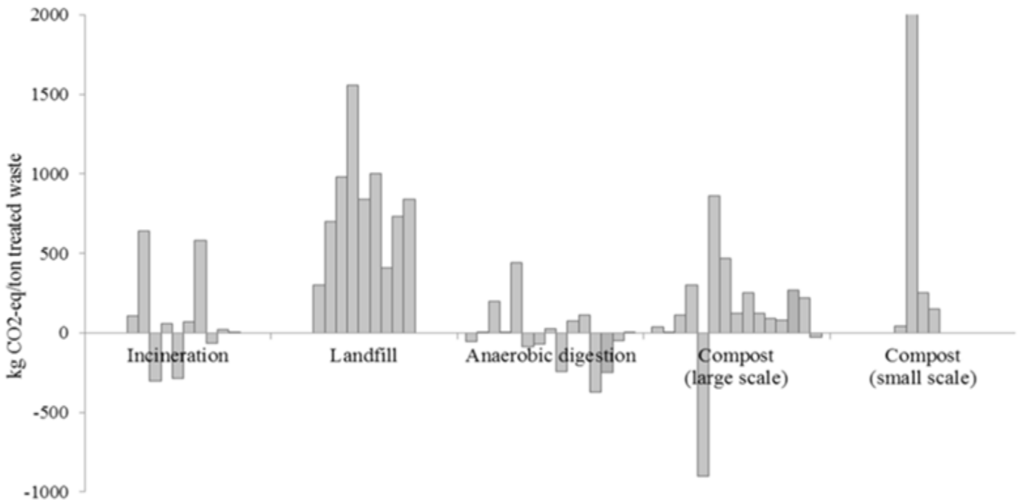


Figure 2.13 Global Warming Potential (GWP) from 1 tonne of food waste treated with different technologies (Bernstad and la Cour Jansen, 2012a)

Composting represents a cost-effective outlet for the producers of compostable wastes and a potential cheap source of organic matter and fertilizer elements for landowners. However, an important key to the success of a composting operation is a marketing or distribution program for compost products (Tweib et al., 2012).

Home composting results in a compost with a high pH (about 9.12 -9.62) and conductivity (EC) (Arrigoni, 2015). The experiments reported by Arrigoni also showed that moisture loss of small waste batches caused variations of temperature and leachate accumulation during the process. Manual mixing could have favored a higher particle specific surface, and therefore a higher microbial decomposition and C loss in the form of CO_2 which would result in a lower organic matter content. During the composting and storage of digestant, losses of mainly nitrogen will also occur (Bernstad et al., 2015).

Landfill contributes about 30% of the global anthropogenic emissions of methane into the atmosphere (Tweib et al., 2012) and causes damage to vegetation, increased groundwater contamination and the possibility of fire and explosions. Furthermore, the pathogenic agents, toxic substances, and gases, together with the bad odors spreading from landfill sites pose risks for public health (Domingo, 2008). Also, the associated loss of land value has meant that landfill, as a means of disposing of FW, has become less popular worldwide.

In modern landfill sites, the impact from the extraction and supplying clay and soil that are used to construct soil covers and impermeable liners, and other upstream input, are not accounted for in most LCAs. Bernstad et al. (2015) stated that with the landfill gas collection (LFG) technology, any collection ratio under 70% will still have great impact on GHG-emission. Pickin (2009) also emphasized that for new landfills, it will cost more to run than for those they replace, especially with "the externality gap between the interests of a private landfill operator and those of the owner of the waste supply". Therefore, "there are no true 'alternatives' to landfill, but rather only ways of slowing down the rate of landfill input". Indeed, LF is the worst option in waste management (Manfredi et al., 2015).

On a 100-year time frame, the emissions rate of GWP100 is at the higher range. Therefore, the IPCC uses a value of 72 for the GWP20 of methane but 21 for the GWP100. Leachate parameters, which are critical indicators for license conditions, such as nitrogen, total dissolved solids, pH or manganese, are not always met by some of the companies responsible for landfill operations (Pickin, 2009).

Thermal waste treatment technologies have still not been fully accepted by governments and environmental scientists. Some researcher argue that IT is a lock-in process. Because the very high costs that have been incurred in investing in IT, it has been suggested that a more sustainable technology will not be developed. This will have a detrimental effect on the introduction of more sustainable MSWM (Massarutto, 2015). Thermal treatment for MSW has been promoted in most developed countries, especially for those with limited land for landfill. It has a significant advantage in reducing the time to process the waste. However, the high-water content, up to 80%, results in a decrease in energy efficiency, leading to an increase in gaseous acidification and an increase in toxic emissions. Thermal treatment needs more energy and resources for the separation of feed stock and pre-treatment of MFW including drying, to 10% water content, before it can be used as fuel material for a thermal process. Therefore, it has less benefit than other organic materials such wood for thermal treatment (Vakalis et al., 2016). After review and analysis of 136 research projects on thermal WtE technologies, Astrup et al. (2014) concluded that upon comparison of IT to recycling, landfill and commercial composting, the recommendation scores are 4 - 25, 22 - 4, and 3 - 4, respectively. It also shows that from the sustainability viewpoint, IT technology scores higher than landfill and close to commercial composting, but it is still lest favorable than recycling.

With FWP, the solids, oils and fats of components will be susceptible to autoxidation and deterioration of the substrate and will restrict the sewage flow if flushed into this system.

With respect to treatment options, influences at the local level include: human and ecological toxicity, different types of resource use, land use and water use, occupational health and safety, working conditions and local environmental impacts such as odor and noise during collection and pre-treatment.

2.4.2 Economic and social impacts

Economic analysis has been done on the cost-benefits involving treatment systems and material flows with a view to achieving sustainable MSW management. Table 2.5 lists the relative economic benefits of different waste treatment systems.

Table 2.3 Relative ecomonic benefits of different treatment systems

Tech-system	Economic
AD	Highest benefit 40% - 80% efficiency (in biogas) (Bernstad et al., 2016a)
CC	"System which include free or unconstrained garden waste collection series tend to be more costly than those which target food waste only" (Eunomia research & consulting, 2007)
IT	23% efficiency (in heat) (Bernstad et al., 2016a)
LF	Any biogas collection rate under 70% will cost financial loss (Bernstad)
FWP	Increase investment in capital or upgrade the facility and sewage system

In dollar terms, it is very difficult to cost an environmental impact. The damage costs of greenhouse gases, for example, are of uncertain magnitude and involve uncertain human impacts and will occur over an uncertain timeframe. Also, effect-by-effect valuation is poor in capturing costs associated with risk. There are huge differences when it comes to cost estimates of environmental impacts from different sources such as the estimates from studies published by the BDA's (BDA Group, 2009) and Murdoch University. For example, for PM10 particulates, these are ($2,700/t and $4,300) to $11,600/t, respectively. And the figure was up to $108,000/t to $221,000/t from CSIRO's Beer's (Beer, 2002) calculation. Furthermore, some potential costs and benefits cannot be readily valued at all and tend to be ignored in most cases. Pickin (2009) used the case of the problems at the Cranbourne landfill as an example to show that "the compensation understood to be under negotiation could soak up all of BDA's estimated landfill amenity costs for the whole of Australia for years or decades".

Bernstad (2012) assessed 218 thermal energy plants and concluded that they resulted in only 2 - 3% return on investment. Hellweg et al. (2005) combined an 'environmental cost-efficiency indicator' with LCA to analysis and compare IT, LF and MBT. He found that IT had the lowest environmental impact compared to LF and MBT, but this was based on a higher financial cost. LF has the highest environmental impact within these three treatment systems.

For composting plants, there are other factors to to be considered: construction costs and materials, user exposure to composting materials and leachate collection and disposal. During the composting process, it will emit volatile organic compounds (VOCs), NH_3 and H_2S by the microbial activity and CH_4 (due to poor air circulation) and a smaller proportion of alkanes, alkenes and cycloalkanes. also, organic dusts carrying various fungi will cause pulmonary inflammation (acute inflammation, hypersensitive pneumounits), occupational asthma, and chronic bronchitis, along with other general health problems such as gastrointestinal disturbances, fevers, and infections and irritations of eyes, ear and skin (Domingo, 2008).

"Market demand is a key factor to make the best use of the available resources and technologies and provide economic feasibility for resource constrained governments." (Ahamed et al., 2016)

Communities are often willing to pay far more for waste management improvements than effect-by-effect valuations indicate is 'rational'. Therefore, it is important that valuations aim to provide a broad view of the range of potential costs and benefits.

Research has confirmed that the separate collection and treatment of HFW in MSW management will significantly influence impacts on the environment, and will even have economic and social impacts (Yoshida et al., 2012, Rigamonti et al., 2009, Matsuda, 2012, Martínez-Blanco et al., 2010, Levis, 2010, Edwards et al., 2016, Dong et al., 2013, Chu et al., 2015, Chi et al., 2015, Bernstad and la Cour Jansen, 2012b). Righi et al. (2013) stated that environmental, economic and social impacts of collection, transportation and disposal/treatment of such waste are of major significance. Therefore, FW treatment management strategies must be based on a systematic approach.

2.5 Conclusions and recommendation

Options of different HFW treatment technologies and management systems are not just associated with environmental issues but are also deeply connected to the economic and social attributes of the generating region. Therefore, to pursue the main objective of sustainable waste management, both in materials and energy recovery, there needs to be public awareness, active commitment and citizen participation. With this in mind, when considering strategies in HFW management, decision-makers should avoid having too narrow a focus on GW and address other aspects such as resource recovery and toxic emissions - as well as economic performance, social acceptance, local involvement, technical robustness, etc.

The concept of a circular economy (CE) (Figure 2.14) has been increasingly gaining acceptance and can be applied to the process of converting resources to consumable goods. It is an alternative to the traditional line-directional waste resources approach where consumption and disposal are seen as the end point of resource utilization. The CE statement of "waste does not exist" is holistic and restorative and may be represented generically by the 'value circle' schematic (Ellen MacArthur Foundation and McKinsey & Company, 2014). CE may change "the structure of a system" (Meadows, 2004). However, this changing may be limited within an industrial economy (Ellen MacArthur Foundation and McKinsey & Company, 2014), especially within the characteristics of FW management systems (Clift et al., 2000). Therefore, when applied to a specific problem (i.e. 'Micro' Circular Economics, MCE) – that potentially involves circular material flows – such as the management of HFW, the framework of CE has become 'less relevant'. The MCE concept focuses on the activities of individuals (say a household), which will build a bridge to explore the relationship between the policy and the individual in the context of economics, the surrounding ecologic environment and a changing society. This will lead to further research at the local level on HFW management within the novel concept of MCE, as shown in Figure 2.15.

With respect to MCE, and in the context of the Medium-Term Strategy of the United Nations Environment Program, a decentralized solution becomes an important option for FW treatment in relation to modern urban planning and development (United Nations General Assembly, 2016). This is especially true with current advances and developments in renewable energy, such as solar and wind power, that are currently in non-continuous and non-flexile supply and which cannot be used as the only renewable source to satisfy residential daily power demands in a reliable way. In this regard, the recovery of energy from food waste generated from our daily lives will become even more important into the future.

Currently, the existing technologies in FWT, internationally, still follow the pattern of collection – separation/industrialization - landfill, together with the associated limitations and disadvantages (shown in Figure 2.16). These will continue to restrict the sustainable development of HFW management and need to be addressed.

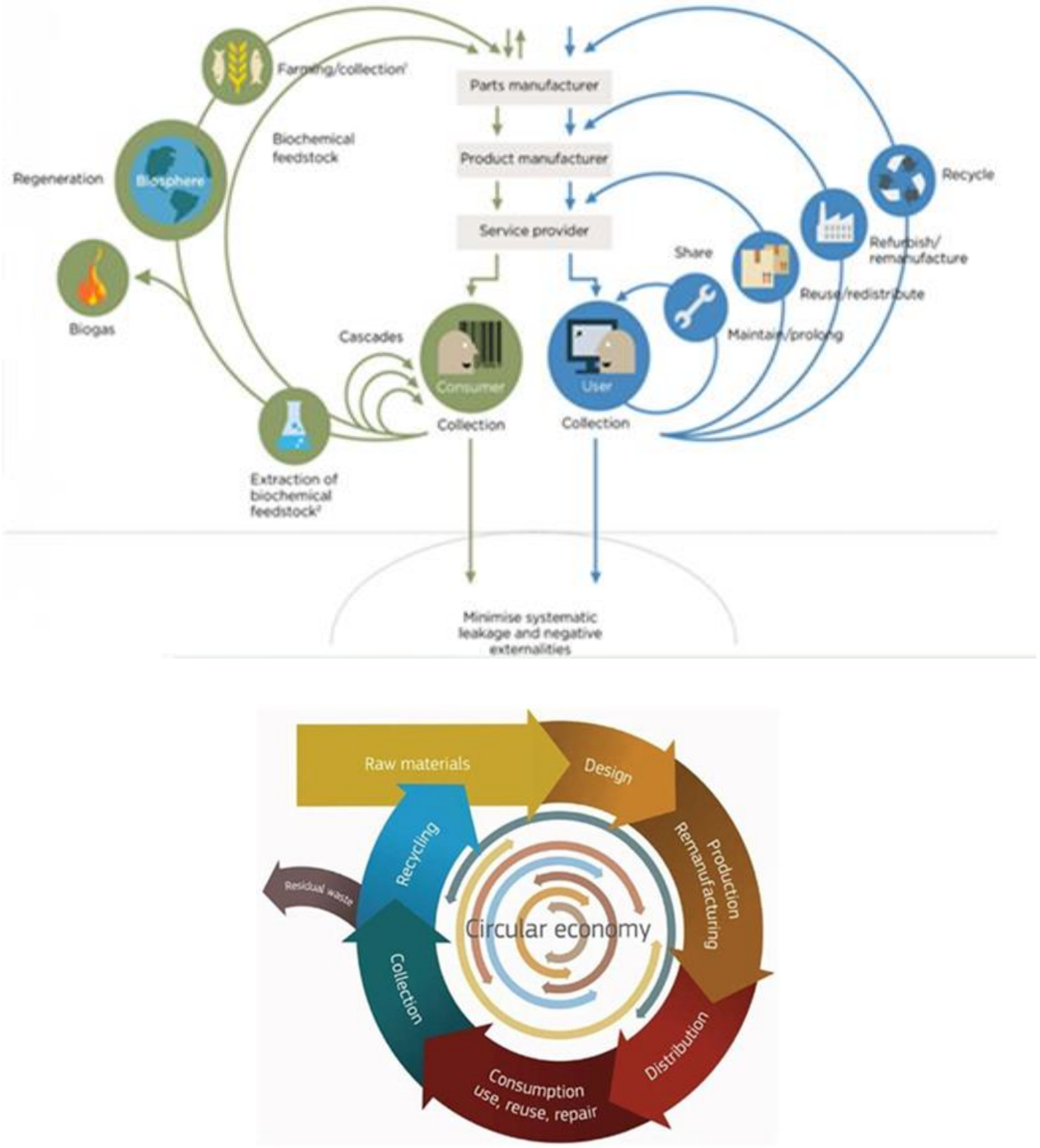


Figure 2.14 The concept of Circular Economy (Ellen MacArthur Foundation and McKinsey & Company, 2014, Gourguignon, 2014)

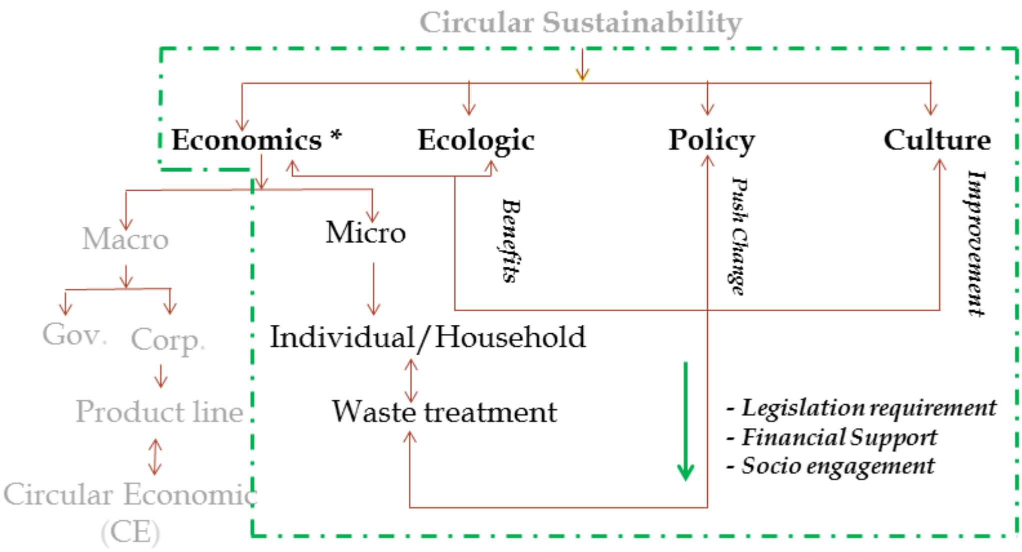


Figure 2.15 The conceptual framework of MCE[5]

Therefore, on-site small-scale AD technology will need to be developed to take advantage of its unique benefits in reducing or replacing the impacts and costs of collection, sorting and transportation and, at the same time, turn the waste into energy and fertilizer - *on site*. It will close the loop of production from the end of food chain and promises to finally achieve the goal of "zero waste" at the micro scale (Figure 2.17). When established and wide-spread, this will translate and be realized on the macro scale.

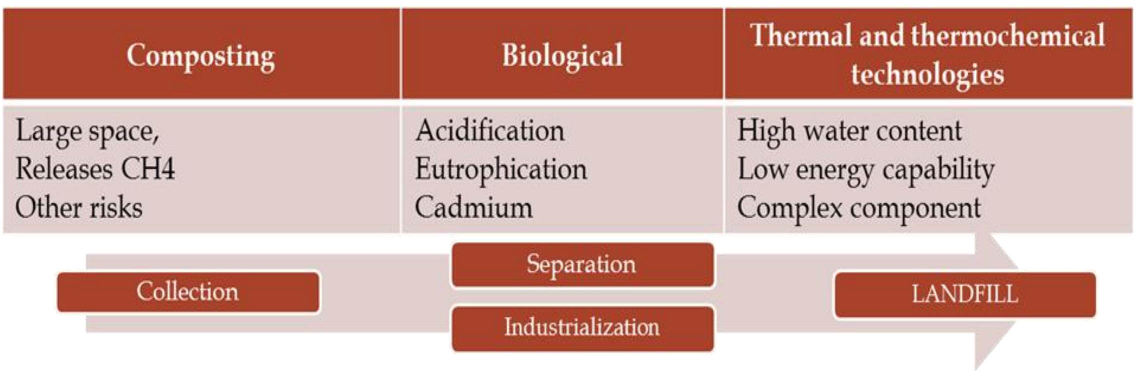


Figure 2.16 Limitations of existing Technologies in FWT internationally (Pham, 2015, Vandermeersch et al., 2014)

[5] This novel concept is an outcome of this thesis and will be developed in future research.

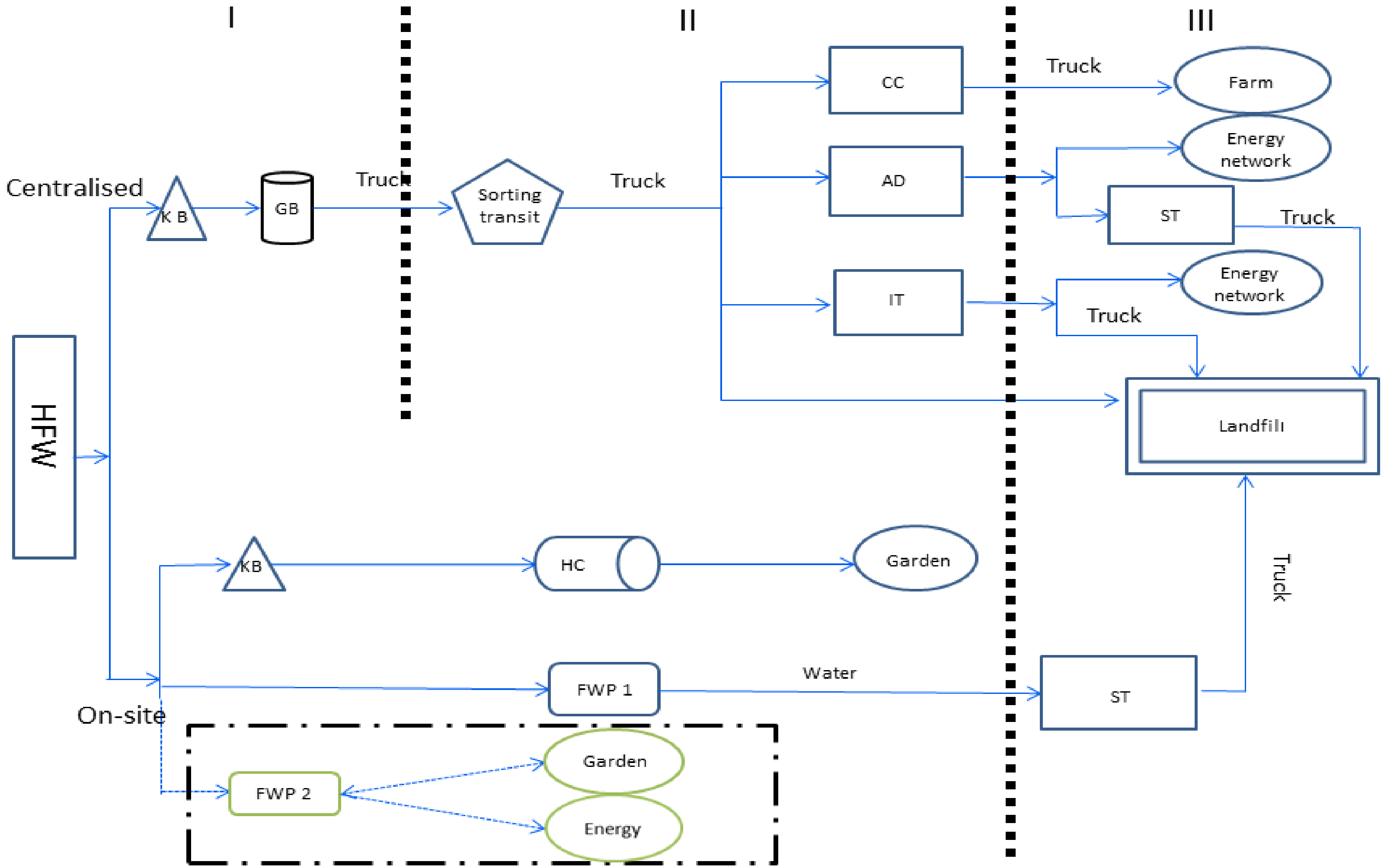


Figure 2.17 Proposed HFW management system map

2.6 References

Abdullah, B, Ma'Radzi, H, Saleh, M, Kamal, Z & Yaacob, D 2011, 'Production of effective microorganism using halal based sources: A review', *African Journal of Biotechnology*, vol. 10, no. 81, pp. 18649-52.

Abeliotis, K, Kalogeropoulos, A & Lasaridi, K 2012, 'Life Cycle Assessment of the MBT plant in Ano Liossia, Athens, Greece', *Waste Management*, vol. 32, no. 1, pp. 213-9.

Ahamed, A, Yin, K, Ng, BJH, Ren, F, Chang, VW-C & Wang, J-Y 2016, 'Life cycle assessment of the present and proposed food waste management technologies from environmental and economic impact perspectives', *Journal of Cleaner Production*.

Ariunbaatar, J 2014, 'Methods to enhance anaerobic digestion of food waste', PhD thesis, Université Paris-Est, via Star Lge Upec-upem, <https://tel.archives-ouvertes.fr/tel-01206170>.

Arrigoni, JPP, Gabriela; Laos, Francisca 2015, 'Feasibility and Performance Evaluation of Different Low-Tech Composter Prototypes', *International Journal of Environmental Protection*, vol. 5, no. 1, p. 1.

Astrup, TF, Tonini, D, Turconi, R & Boldrin, A 2014, 'Life cycle assessment of thermal Waste-to-Energy technologies: Review and recommendations', *Waste Management*, vol. 37, pp. 104-15.

BDA Group 2009, *The full cost of landfill disposal in Australia*, Australia Government.

Beer, T 2002, 'Valuation of Pollutants Emitted by Road Transport into the Australian Atmosphere', in *16th International Clean Air & Environment Conference*, Christchurch, N.Z., p. 5.

Bernstad, A 2012, 'Household food waste management–Evaluations of current status and potential improvements using life-cycle assessment methodology', Lund University.

Bernstad, A, Davidsson, Å & Bissmont, M 2016, 'Lifecycle assessment of a system for food waste disposers to tank – A full-scale system evaluation', *Waste Management*, vol. 54, pp. 169-77.

Bernstad, A & la Cour Jansen, J 2011, 'A life cycle approach to the management of household food waste – A Swedish full-scale case study', *Waste Management*, vol. 31, no. 8, pp. 1879-96.

Bernstad, A & la Cour Jansen, J 2012a, 'Review of comparative LCAs of food waste management systems – Current status and potential improvements', *Waste Management*, vol. 32, no. 12, pp. 2439-55.

—— 2012b, 'Separate collection of household food waste for anaerobic degradation – Comparison of different techniques from a systems perspective', *Waste Management*, vol. 32, no. 5, pp. 806-15.

Bernstad, A, Wenzel, H & Jansen, JlC 2015, 'Identification of decisive parameters in LCA of food waste management-an analytical review', *Journal of Cleaner Production*.

Bernstad, A, Wenzel, H & la Cour Jansen, J 2016, 'Identification of decisive factors for greenhouse gas emissions in comparative lifecycle assessments of food waste management–An analytical review', *Journal of Cleaner Production*, vol.

Bhander, GS, Christensen, TH & Hauschild, MZ 2010, 'EASEWASTE—life cycle modeling capabilities for waste management technologies', *The International Journal of Life Cycle Assessment*, vol. 15, no. 4, pp. 403-16.

Boulding, KE 1966, 'the Economics of the Coming Spaceship Earth'

Bovea, MD, Ibáñez-Forés, V, Gallardo, A & Colomer-Mendoza, FJ 2010, 'Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study', *Waste Management*, vol. 30, no. 11, pp. 2383-95.

Carre, A, Crossin, E & Clune, S 2015, *LCA of kerbside recycling in Victoria*, 1.3, RMIT University.

Cherubini, FB, S; Ulgiati, S 2009, 'Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration', *Energy*, vol. 34, no. 12, pp. 2116-23.

Cherubini, FS, A. 2011, 'Life cycle assessment of bioenergy systems: State of the art and future challenges', *Bioresource Technology*, vol. 102, no. 2, pp. 437-51.

Chi, Y, Dong, J, Tang, Y, Huang, Q & Ni, M 2015, 'Life cycle assessment of municipal solid waste source-separated collection and integrated waste management systems in Hangzhou, China', *Journal of Material Cycles and Waste Management*, vol. 17, no. 4, pp. 695-706.

Chiu, SLH, Lo, IMC, Woon, KS & Yan, DYS 2015, 'Life cycle assessment of waste treatment strategy for sewage sludge and food waste in Macau: perspectives on environmental and energy production performance', *The International Journal of Life Cycle Assessment*, vol. 21, no. 2, pp. 176-89.

Chu, T-W, Heaven, S & Gredmaier, L 2015, 'Modelling fuel consumption in kerbside source segregated food waste collection: separate collection and co-collection', *Environmental technology*, vol. 36, no. 23, pp. 3013-21.

Clift, R, Doig, A & Finnveden, G 2000, 'The Application of Life Cycle Assessment to Integrated Solid Waste Management', *Process Safety and Environmental Protection*, vol. 78, no. 4, pp. 279-87.

Dellinger, AR 2013, 'Economic feasibility and environmental analysis of a municipal food waste collection and anaerobic digestion program model', Master of Science thesis, The University of Toledo.

Department of Economic and Social Affairs of the United Nations Secretariat 2013, *Sustainable Development Challenges --World Economic and socail Survey 2013*.

Diener, RG, Collins, AR, Martin, JH & Bryan, WB 1993, 'Composting of source-separated municipal solidwaste for agricultural utilization a conceptualapproach for closing the loop.', *Food and Agriculture Organization of the United Nations*, vol. 9, no. 5.

Domingo, JLN, M 2008, 'Domestic waste compoting facilities: a review of human health risks', *Environment International*, vol. 35, no. 2009, pp. 382-9.

Dong, J, Ni, M, Chi, Y, Zou, D & Fu, C 2013, 'Life cycle and economic assessment of source-separated MSW collection with regard to greenhouse gas emissions: a case study in China', *Environmental Science and Pollution Research*, vol. 20, no. 8, pp. 5512-24.

Dou, X 2015, 'Food waste generation and its recycling recovery: China's governance mode and its assessment', *future*, vol. 2, p. 3.

Edwards, J, Othman, M, Burn, S & Crossin, E 2016, 'Energy and time modelling of kerbside waste collection: Changes incurred when adding source separated food waste', *Waste Management*.

Ellen MacArthur Foundation 2015, *Circular Economy Overview*2017, <https://www.ellenmacarthurfoundation.org/>.

Ellen MacArthur Foundation and McKinsey & Company 2014, *Towards Circular Economy: Accelerating the scale-up across global supply chains*, World Economic Forum, Geneva, Switzerland.

Eriksson, O, Carlsson Reich, M, Frostell, B, Björklund, A, Assefa, G, Sundqvist, JO, Granath, J, Baky, A & Thyselius, L 2005, 'Municipal solid waste management from a systems perspective', *Journal of Cleaner Production*, vol. 13, no. 3, pp. 241-52.

Eunomia research & consulting 2007, *Managing Biowastes from Households in the UK: Applying Life-cycle Thinking in the Framework of Cost-benefit Analysis*, WRAP, Bristol BS1 4HW, <www.wrap.org.uk/sites/files/wrap/Biowaste_CBA_Final_Report_May_2007.pdf>.

Feo, GD & Malvano, C 2009, 'The use of LCA in selecting the best MSW management system', *Waste Management*, vol. 29, no. 6, pp. 1901-15.

Food and Agriculture Organization of the United Nations 2011, *Global food losses and food waste - extent, causes and prevention*, Rome, <http://www.fao.org/docrep/>.

Giusti, L 2009, 'A review of waste management practices and their impact on human health', *Waste Management*, vol. 29, no. 8, pp. 2227-39.

Gourguignon, D 2014, *Turnng waste into a resource moving towards a 'circular economy'*, 8, European Parliament, <www.europarl.euroa.eu/thinktank>.

Güereca, LP, Gassó, S, Baldasano, JM & Jiménez-Guerrero, P 2006, 'Life cycle assessment of two biowaste management systems for Barcelona, Spain', *Resources, Conservation and Recycling*, vol. 49, no. 1, pp. 32-48.

Hellweg, S, Doka, G, Finnveden, G & Hungerbuhler, K 2005, 'Assessing the Eco-efficiency of End-of-Pipe Technologies with the Environmental Cost Efficiency Indicator', *Journal of Industrial Ecology*, vol. 9, no. 4.

Hertwich, EG 2005, 'Life Cycle Approaches to Sustainable Consumption: A Critical Review', *Environmental Science and Technology*, vol. 39, no. 13, pp. 4673-84.

Hill, AL 2010, 'Life cycle assessment of municipal waste management: improving on the waste hierarchy', Master thesis, Aalborg University.

Hoefnagels, RS, Edward; Faaij, André 2010, 'Greenhouse gas footprints of different biofuel production systems', *Renewable and Sustainable Energy Reviews*, vol. 14, no. 7, pp. 1661-94.

Iacovidou, EO, Dieudonne-Guy; Gronow, Jan; Voulvoulis, Nikolaos 2012, 'The household use of food waste disposal units as a waste management option: a review', *Critical reviews in environmental science and technology*, vol. 42, no. 14, pp. 1485-508.

Khoo, HH, Lim, TZ & Tan, RBH 2010, 'Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective', *Science of The Total Environment*, vol. 408, no. 6, pp. 1367-73.

Koroneos, C & Nanaki, E 2012, 'Integrated solid waste management and energy production - a life cycle assessment approach: the case study of the city of Thessaloniki', *Journal of Cleaner Production*, vol. 27, pp. 141-50.

Korse, M 2015, 'A Business Case Model to Make Sustainable Investment Decisions - Adding Circular Economy to Asset Management', Master thesis, University of Twente.

Kosovska, H 2006, 'THE BIOLOGICAL TREATMENT OF ORGANIC FOOD WASTE', Master thesis, Royal Institute of Technology.

Laurent, A, Bakas, I, Clavreul, J, Bernstad, A, Niero, M, Gentil, E & Hauschild, MZC, Thomas H 2014, 'Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives', *Waste Management*, vol. 34, no. 3, pp. 573-88.

Laurent, A, Clavreul, J, Bernstad, A, Bakas, I, Niero, M, Gentil, E, Christensen, TH & Hauschild, MZ 2014, 'Review of LCA studies of solid waste management systems ? Part II: Methodological guidance for a better practice', *Waste Management*, vol. 34, no. 3, pp. 589-606.

Levis, JW, Barlaz, MA, Themelis, NJ & Ulloa, P 2010, 'Assessment of the state of food waste treatment in the United States and Canada', *Waste Management*, vol. 30, no. 8, pp. 1486-94.

Levis, JWB, M A; Themelis, N J; Ulloa, P 2010, 'Assessment of the state of food waste treatment in the United States and Canada', *Waste Management*, vol. 30, no. 8, pp. 1486-94.

Li, ZH, G; Yu, H; Zhou, Y; Huang, W 2015, 'Critical factors and their effects on product maturity in food waste composting', *Environmental Monitoring and Assessment*, vol. 187, no. 4, pp. 1-14.

Lombardi, LC, Ennio; Corti, Andrea 2015, 'A review of technologies and performances of thermal treatment systems for energy recovery from waste', *Waste Management*, vol. 37, pp. 26-44.

Lundie, S & Peters, G 2005, 'Life cycle assessment of food waste management options', *Journal of Cleaner Production*, vol. 13, no. 3, pp. 275-86.

Manfredi, S & Christensen, TH 2009, 'Environmental assessment of solid waste landfilling technologies by means of LCA-modeling', *Waste Management*, vol. 29, no. 1, pp. 32-43.

Manfredi, S, Cristobal, J, Cristina, M, Giavini, M, Vasta, A, Sala, S, Saouter, E & Tuomisto, H 2015, *Improving Sustainability and Circularity of European Food Waste*

Management with a Life Cycle Approach, EUR 27657 EN, the European Commission, DOI 10.2788/559411.

Martínez-Blanco, J, Colón, J, Gabarrell, X, Font, X, Sánchez, A, Artola, A & Rieradevall, J 2010, 'The use of life cycle assessment for the comparison of biowaste composting at home and full scale', *Waste Management*, vol. 30, no. 6, pp. 983-94.

Mason, LB, T; Fyfe, J; Smith, T; Cordell, D 2011, *National food waste assessment-final report*, Institute for Sustainable Futures, UTS.

Massarutto, A 2015, 'Economic aspects of thermal treatment of solid waste in a sustainable WM system', *Waste Management*, vol. 37, pp. 45-57.

Matsuda, TY, Junya; Hirai, Yasuhiro; Sakai, Shin-ichi 2012, 'Life-cycle greenhouse gas inventory analysis of household waste management and food waste reduction activities in Kyoto, Japan', *The International Journal of Life Cycle Assessment*, vol. 17, no. 6, pp. 743-52.

Meadows, HR, J.; Meadows, LD 2004, *The limits to growth : the 30-year update*, White River Junction, Vt : Chelsea Green Publishing Company, US.

Merrild, H, Larsen, AW & Christensen, TH 2012, 'Assessing recycling versus incineration of key materials in municipal waste: The importance of efficient energy recovery and transport distances', *Waste Management*, vol. 32, no. 5, pp. 1009-18.

Messina, A 2012, *Sustainability measurement handbook*, Delhi : University Publications; 1st ed.

Mirabella, NC, Valentina; Sala, Serenella 2014, 'Current options for the valorization of food manufacturing waste: a review', *Journal of Cleaner Production*, vol. 65, pp. 28-41.

Nair, J & Okamitsu, K 2010, 'Microbial inoculants for small scale composting of putrescible kitchen wastes', *Waste Management*, vol. 30, no. 6, pp. 977-82.

Nakakubo, T, Tokai, A & Ohno, K 2012, 'Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery', *Journal of Cleaner Production*, vol. 32, pp. 157-72.

Ohtaki, AA, N; Nakasaki, K 1998, 'Effects of temperature and inoculum on the degradability of poly-ε-caprolactone during composting', *Polymer Degradation and Stability*, vol. 62, no. 2, pp. 279-84.

Oxford Dictionaries n.d., *Developing country*, Oxford University Press <http://www.oxforddictionaries.com>.

Palmer, P 2004, *Getting to Zero Waste*, Purple Sky Press.

Pham, TK, R; Parshetti, G K.; Mahmood, R; Balasubramanian, R 2015, 'Food waste-to-energy conversion technologies: Current status and future directions', *Waste Management*, vol. 38, no. 0, pp. 399-408.

Pickin, J 2009, *Peer review of The full cost of landfill disposal in Australia*, The Department of the Environment, Water, Heritage and the Arts.

Pires, A, Martinho, G & Chang, N-B 2011, 'Solid waste management in European countries: A review of systems analysis techniques', *J Environ Manage*, vol. 92, no. 4, pp. 1033-50.

Recycled Organics Unit 2007, *Recycled organics dictionary and thesaurus*, 3nd edn, The university of New South Wales, <http://www.recycledorganics.com/index.htm>.

Rigamonti, L, Grosso, M & Giugliano, M 2009, 'Life cycle assessment for optimising the level of separated collection in integrated MSW management systems', *Waste Management*, vol. 29, no. 2, pp. 934-44.

Righi, S, Oliviero, L, Pedrini, M, Buscaroli, A & Della Casa, C 2013, 'Life Cycle Assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches', *Journal of Cleaner Production*, vol. 44, pp. 8-17.

Rousta, K, Richards, T & Taherzadeh, MJ 2015, 'An Overview of Solid Waste Management toward Zero Landfill: A Swedish Model', in MJ Taherzadeh & T Richards (eds), *Resource Recovery to Approach Zero Municipal Waste*, CRC Press, NY.

Slagstad, H & Brattebø, H 2012, 'LCA for household waste management when planning a new urban settlement', *Waste Management*, vol. 32, no. 7, pp. 1482-90.

Song, Q, Wang, Z & Li, J 2013, 'Environmental performance of municipal solid waste strategies based on LCA method: a case study of Macau', *Journal of Cleaner Production*, vol. 57, pp. 92-100.

Takata, M, Fukushima, K, Kawai, M, Nagao, N, Niwa, C, Yoshida, T & Toda, T 2013, 'The choice of biological waste treatment method for urban areas in Japan—An environmental perspective', *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 557-67.

Tampio, E, Ervasti, S, Paavola, T, Heaven, S, Banks, C & Rintala, J 2014, 'Anaerobic digestion of autoclaved and untreated food waste', *Waste Manag*, vol. 34, no. 2, pp. 370-7.

Thiele, L 2013, *Sustainability*, 1 edn, Polity Press, UK, <http://VU.eblib.com.au>.

Tonini, D, Martinez-Sanchez, V & Astrup, T 2013, 'Material Resources, Energy, and Nutrient Recovery from Waste: Are Waste Refineries the Solution for the Future?', *Environmental Science & Technology*, vol. 47, no. 15, pp. 8962-9.

Transpacific 2014, *Sustainability report 2014*, Transpacific.

Tsang, Y-l 曾 2013, 'Feasibility of a food waste to energy system in high-rise buildings', Master thesis, The University of Hong Kong, <http://hdl.handle.net/10722/194574>.

Tunesi, S 2011, 'LCA of local strategies for energy recovery from waste in England, applied to a large municipal flow', *Waste Management*, vol. 31, no. 3, pp. 561-71.

Turner, D, Williams, I & Kemp, S 2016, 'Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making', *Journal of Cleaner Production*, vol. 129, pp. 234-48.

Tweib, SA, Rahman, RA & Khalil, M 2012, 'A Literature Review on the Composting', in *International Conference on Environment and Industrial Innovation*.

UNEP 2014, *Assessing Global Land Use: balancing consumption with sustainable supply*.

United Nations 2014, *System of Environmental-Economic Accounting 2012- Central Framework*, ST/ESA/STAT/SerF/109, United Nations, New York, DOI ISBN: 987-92-1-161563-0.

United Nations General Assembly 2016, *Promotion of new and renewable sources of energy*, United Nations.

USEPA 2000, *Onsite Wastewater Treatment Systems - Special Issues Fact Sheet 2. High-Organic-Strength Wastewaters (Including Garbage Grinders)*.

Vakalis, S, Sotiropoulos, A, Moustakas, K, Malamis, D, Vekkos, K & Baratieri, M 2016, 'Thermochemical valorization and characterization of household biowaste', *J Environ Manage*.

Vandermeersch, T, Alvarenga, RAF, Ragaert, P & Dewulf, J 2014, 'Environmental sustainability assessment of food waste valorization options', *Resources, Conservation and Recycling*, vol. 87, pp. 57-64.

Vandermeersch, TA, R. A. F.; Ragaert, P.; Dewulf, J. 2014, 'Environmental sustainability assessment of food waste valorization options', *Resources, Conservation and Recycling*, vol. 87, no. 0, pp. 57-64.

Viganò, F, Consonni, S, Grosso, M & Rigamonti, L 2010, 'Material and energy recovery from Automotive Shredded Residues (ASR) via sequential gasification and combustion', *Waste Management*, vol. 30, no. 1, pp. 145-53.

Wikiperdia n.d., *Compost*2015, <https://en.wikipedia.org/wiki/Compost>.

WSN Environmental Solution 2005, *Your easy guide to waste technologies*, 36, WSN Environmental Solution.

Xi, BZ, G; Liu, H 2005, 'Process kinetics of inoculation composting of municipal solid waste', *Journal of Hazardous Materials*, vol. 124, no. 1–3, pp. 165-72.

Yoshida, H, Gable, JJ & Park, JK 2012, 'Evaluation of organic waste diversion alternatives for greenhouse gas reduction', *Resources, Conservation and Recycling*, vol. 60, pp. 1-9.

Zafar, S 2014, 'Biomass resources from rice industry', *Bioenergy consult*, *http://www. bioenergyconsult. com/biomass-resourcesrice-industry*.

Zaman, A & Reynolds, C 2015, 'The economic and bio-energy production potential of South Australian food waste using Anaerobic digestion', in *Unmaking Waste 2015* Adelaide, South Australia, p. 12.

Zaman, AU 2010, 'Comparative study of municipal solid waste treatment technologies using life cycle assessment method', *International Journal of Environmental Science & Technology*, vol. 7, no. 2, pp. 225-34.

Zhang, C, Su, H, Baeyens, J & Tan, T 2014, 'Reviewing the anaerobic digestion of food waste for biogas production', *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 383-92.

Zhang, Q, Hu, J & Lee, D-J 2016, 'Biogas from anaerobic digestion processes: Research updates', *Renewable Energy*.

Zhang, R, El-Mashad, HM, Hartman, K, Wang, F, Liu, G, Choate, C & Gamble, P 2007, 'Characterization of food waste as feedstock for anaerobic digestion', *Bioresource Technology*, vol. 98, no. 4, pp. 929-35.

Zhang, ZX, S; et al. 2014, 'The research of Municipal Solid Waste Incineration Technology', *Guangzhou Chemical Industry*, vol. 2014, no. 17.

Zhao, Y, Christensen, TH, Lu, W, Wu, H & Wang, H 2010, 'Environmental impact assessment of solid waste management in Beijing City, China', *Waste Management*, vol. 31, no. 4, pp. 793-9.

Zhao, Y & Deng, W 2014, 'Environmental impacts of different food waste resource technologies and the effects of energy mix', *Resources, Conservation and Recycling*, vol. 92, pp. 214-21.

Zschokke, M, Kagi, T & Dinkel, F 2012, 'Comparing environmental impacts of end-of-life treatments of food waste', in *LCA Food Conference*, Saint-Malo.

SA Government 2010, *Valuing our food waste South Australia's household food; waste recycling pilot summary report*, by ZWSA.

Chapter 3: Commentary on international HFW management

3.1 Introduction

As mentioned in Chapter 2, HFW treatment and management systems are closely linked and affected by a country's GDP, education, transparency index, social behavior, policy planning, appropriate technology, waste collection, characterization and separation techniques, religions, market for recycled material and people's awareness of sustainable cities. The current LCAs are mostly set up within a computer modelling framework. However, any modelling is only a programming object and is purely coincidental to the real-world (Jackson, 1975). Therefore, for 'real-world' objects, case studies have become essential when considering the selection of a HFW management system - and there is no Silver Bullet.

The major HFW management systems worldwide are readily traceable. Most countries are divided into two groups on the basis of economic and social factors, namely, the developed/industrialized and the developing/disadvantaged countries (The World Bank, n.d., Oxford Dictionaries, n.d.). The International Statistical Institute extends this definition, where the Gross National Income (GNI) of US$11,905 per capita per year is the dividing line between these two groups (Thi et al., 2015).

Research has shown that the average amount of FW per capita generated from developed countries is twice that of developing countries (Dung et al., 2014). Within developed countries, FW is generated mostly by consumers, with the amount being more than 40% of the total FW generated from the food production chain. With developing countries, the amount is under 20% for the total FW generated from the food production chain (Xu et al., 2018). Therefore, each individual country has its profile with respect to FW management practice. HFW treatment and management systems for some representative countries are described briefly as follows.

3.2 Developed countries

3.2.1 The EU

In Europe, the amount of FW generated was predicted to increase from 98 million tons to 139 million tons by 2020 (European Commission, 2011). For environmental protection and sustainability, a series of policies and programs focused on reducing FW have been formulated and implemented. These prevention policies or activities target stakeholders directly. They included the UK's (no longer EU) Waste and Resources Action Programme (WRAP) and National Industrial Symbiosis Programme, Italy's Eco-point Initiative, Austria's Vienna Waste Prevention Programme, Portugal's Menu Dose Certa, France's Stop-Pub, and Belgium's Kringloop Re-use Centres. Enabling legislation to support these initiatives include: The Landfill Directive 1999/31/EC, Thematic Strategy on the Prevention and Recycling of Waste 2005, Directive 2006/12/EC (Monier, 2010) and the Waste Framework Directive (WFD 2008/98/EC). All consist of detailed strategies for EU's future waste management and define the targets for waste prevention. Policies relating to treatment technologies have developed alongside landfill reduction targets and have achieved a significant impact on FW prevention.

Also, the European Commission has proposed "A Bio-economy for Europe" to promote innovation of bio-products and energy from FW for sustainable growth in Europe. Research from Lamb (2010) has demonstrated that home composting and FW digesters represent major on-site HFW methods and have been combined with central treatment in dealing with more than 1.5 million tonnes of HFW. However, due to space restrictions and other reasons, composting has not been promoted in urban areas and only deals with 10% of the FW stream (Eunomia research & consulting, 2007). Meanwhile, Knipe (2006) reported that home FW digester are more acceptable by the public because of less frequent collection and resource recycling requirements. Lombardi (2015) states that there is only 2.6% of renewable electricity produced from MSW thermal treatment in EU27. The separate collection of biodegradable waste and its biological treatment with subsequent material and/or energy recovery is seen as an optimum approach and one increasingly practiced in the EU-27. The research done by Righi et al (2013) stated that European had installed anaerobic digestion capacity was about 6 Mt per year divided over 200 plants, with an average capacity of 30,000 t per year in the period of study. Recently, a pilot-scale study – called the For Biogas project, which is based on 51 anaerobic digestion technology, has been developed both by university and local stakeholders so as to assess the technical, economic and environmental feasibility of an integrated and decentralized bio-waste treatment system (Righi et al., 2013). However, for countries like Greece, Estonia, Cyprus and Malta, landfilling is still the standard method for waste disposal with diversion-to-landfill percentages over 60%, compared to 20% in seven more industrialised countries (Bernstad, 2012, European Commission, 2015).

3.2.2 USA

In the USA, the FW generated has increased by 50% since 1974. This adds up to 38 million tons each year. 76.3% of this is disposed of to landfill, costing billions of dollars. In fact, FW issues represent up to US$77 billion annually in the America economy and this figure continues to increase (Posmanik et al., 2017, Melikoglu et al., 2013, USAEPA, 2016).

With HFW management, along with other household waste, collection and treatment is operated by government licensed commercial companies. Biological treatment facilities are well-developed but do not include composting. Furthermore, under a quarter of these facilities accept HFW (Levis, 2010). To reduce FW sent to landfill, HFW processor installation has become the standard recommended by the US Green Building Council (USGBC) in building and kitchen design as articulated by the LEED (Leadership in Energy and Environmental Design) guidelines[6].

Meanwhile 7.4 % of MSW is fed to thermal treatment plants as WtE fuel. It contributes 28% of renewable electric energy in the USA (Lombardi, 2015).

3.2.3 Japan

In Japan, about 40% of food production (19 million tonnes annually) is thrown away (Melikoglu et al., 2013). In the early 21st century, the 2001 Food Recycling Law was set up to mandate a CE approach to be utilized within the food industry (Takata et al., 2012). However, a lack of land availability and cost factors associated with composting have

[6] http://www.cn-hw.net/html/sort054/201201/31549.html

resulted in incineration technology (IT) remaining as the most common treatment method for HFW disposal (Inaba, 2010, Matsuda, 2012). Japan is also the largest user of MSW thermal treatment internationally. 80% of MSW is incinerated with 24.5% of this involving IT and WtE processes. The energy and material recovery are mainly from commercial scale gasification (Lombardi, 2015).

3.3 Developing countries

3.3.1 China

In China, there is more than 90 million tons of FW generated annually in total. About quarter of this amount is HFW. This is about 16 kg per capita per year, which is lower than the 95-115 kg per capita per year for developed countries such as Europe and North America - but it is higher than the 6-11 kg per capita per year for developing countries such as sub-Saharan Africa and South/Southeast Asia (Chen et al., 2010, Thi et al., 2015, Zhang et al., 2014). These amounts have been continuing to increase due to the rapid growth of urban populations. Also, inside China, the figure varies depending on the 'grade' of the city. Chinese cities have been divided into five grades depending on the political geography, population and economic condition of the city. 19 cities, including Beijing and Shanghai, are designated first-tier cities, and there are 36 second-tier cities, 74 third-tier cities and others that are designated fourth and fifth tier cities. However, due to high population growth and rapid urbanization, the total MSW generation in China is the highest in the world (e.g. in 2004 in one year alone it reached 190 million tonnes) (Chen et al., 2010). Chinese local governments have responded to the collection and processing of household waste in urban areas. But, in recent years, local government is slowly passing the duties to commercial companies. Meanwhile, the MSW management methods have depended upon a city's financial capacity, the geographical environment and so on. Nevertheless, HFW represents the highest proportion of MSW overall, being around 60% for all cities (Zhang, 2010, Song, 2015). Landfill and incineration are the major treatment methods positioned first and second respectively in the first and second-tier cities (Cheng, 2010, Zhang, 2010) that treat over 93.6% of MSW. IT not only aims to reduce the volume of waste but also aims to achieve energy recovery, albeit with an efficiency of only 17% with respect to gross electricity conversion (Lombardi, 2015).

Following increasing concern about air pollution in the first-tier cities, the government has forced a change in management strategy and the adoption of new technology, such as biological and mechanical pre-treatment, along with LF and IT, into MSW management (Hong, 2006). This acknowledges the technological challenges associated IT such as difficulty in ignition, unsteady and unstable combustion flame, incomplete combustion of the waste and increased formation of air pollution (Lombardi, 2015). It is also acknowledged that IT requires huge additional investment.

In the lower-tier cities and rural areas, biological treatment has been promoted with respect to daily garbage collection (Yu, 2008) as well as LF. In spite of the Chinese government funding 100 FW treatment pilot plants in 100 cities (Wen et al., 2016), the challenges in FW management still remains as an important imperative (Chen et al., 2010).

3.3.2 India

India, which together with China, forms 37% of the total global population, generates 72 million tonnes of FW per year (Bureau Population Reference, 2014). Nixon et al. (2013) also stated that only about 70% of MSW was collected. So, the amount of FW is likely to be higher.

In India, LF is the major treatment method for MSW and 90% of these are open sites. The second treatment method is composting and is there are very few other treatments technologies (Annepu, 2012, Lombardi, 2015).

3.3.3 Other developing countries

In other developing countries FWT faces severe challenges due to inadequate basic public FWM systems (Thi et al., 2015, The World Bank, n.d.). Investments for MSWM have been focused mainly on collection and landfill, being up to 80% of the total MSWM budget compared to 10% for developed countries (Modak, 2011).

3.4 Australia

In Australia, the average per capita amount of HFW per year is the highest in the World (Transpacific Industries Group Ltd, n.d.). With the continuing growth of the population, the issue of FWM has become important to the Nation's sustainability. In this regard, there are significant studies examining FWM in Australia including reports from the Recycled Organics Unit (2011), Recycled Organics Unit (2009), Recycled Organics Unit (2010), Recycled Organics Unit (2008), Recycled Organics Unit (2007a), Recycled Organics Unit (2006).

In Australia, household food waste (HFW) is the largest component of domestic waste and makes up 68% of total municipal solid waste (MSW). It is estimated that, on average, each Australian disposes of 414 kg of food waste (FW) per year (Transpacific Industries Group Ltd, n.d.). The research from Transpacific Industries Group Ltd (n.d.) showed that, in 2004 alone, an estimated $5.2 billion worth of food was wasted nationally. Table 3.1 shows that the state of Victoria generated over 84 thousand tonnes of FW from 2009 to 2010, which was nearly the same amount of the 27 EU countries combined. Furthermore, around 82% of collected FW was sent to landfill in Victoria over the 2010 – 2011 financial year (Table 3. 2). In addition to this figure, which represents formal disposal methods, it is estimated that an extra 20% of HFW was disposed of through 'informal routes' such as home composting, kitchen in-sink-blender, etc. (Reynolds, 2014). Thus, the existing FW treatment regime in Victoria (as illustrated in Tables 3.1-3, Figure 3.1) contributes to greenhouse gas (GHG) emissions and negatively impacts on the environment, also resulting in significant economic losses. Indeed, the complex sustainability challenges associated with HFW disposal in general have become increasingly urgent.

A number of significant studies have outlined some of the problems of food waste management (FWM). For example, Mason (2011) has identified the gaps in FWM research from pre-farm gate, to post-farm gate to check-out. In this regard, these authors have stated that their research on final stage (check-out to waste bin) processes has proven particularly challenging due to geographical coverage, methodology and sampling issues, and especially due to the lack of standard auditing guidelines.

Table 3.1 FW received/processed in Australia and Victoria (tonnes/per financial year) (Australian Government Department of the Environment, 2013, Recycled Organics Unit, 2011, Recycled Organics Unit, 2010, Recycled Organics Unit, 2009, Recycled Organics Unit, 2008, Recycled Organics Unit, 2007a, Recycled Organics Unit, 2006, Randell et al., 2014)

Time	National	Victoria
2010-2011	150,555	22,368
2009-2010	211,775	84,120
2008-2009	136,089	12,966
2007-2008	124,023	5,796
2006-2007	79,272	N/A
2005-2006	81,866	25,796

Table 3.2 FW generation and treatment as a percentage of the total FW generation in Australia and Victoria from 2010 -2011, by treatment method type (Australian Government Department of the Environment, 2013)

Waste treatment	FW / Total MSW	Victoria	National
Disposal to landfill	764,089 / 1,000,710	82%	57%
Recycling	-	2%	-

Table 3.3 The cost of FW treatment in Victoria for the financial year (FY) 2012-2013 (Sustainability Victoria, 2015)

Tonnes collected	1,102,150
No. households	2,359,764
Total cost	$229.6 million
Collected per household (kg/yr)	467 kg (7% increasing)
Cost per household (yr)	$ 97.29 (This cost had 7.8 % increased, it is more than three times of the Consumer Price Index (CPI) of 2.2 % increased in some period of one-year time. It increased 99.1% for over ten years' time)

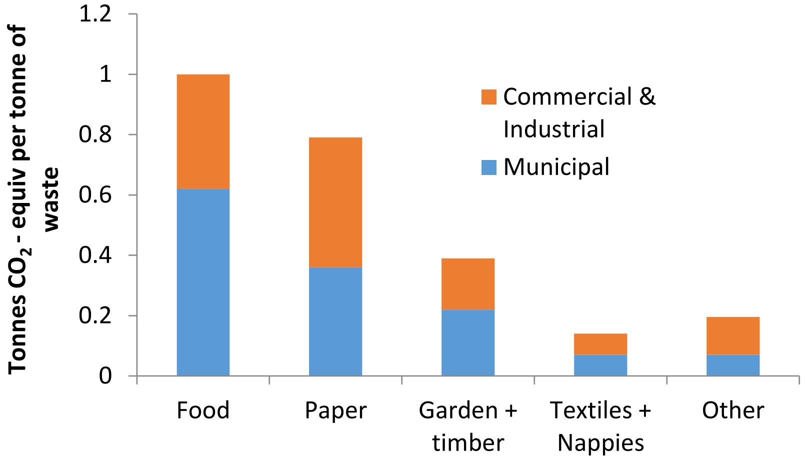


Figure 3.1 Waste GHG generated from landfill site components (reproduced from The Office of Parliamentary Counsel (2008)

Furthermore, research by Adhikari (2010), Zschokke et al. (2012) and ZWSA (2010) show that households have an increasing preference to use informal disposal methods rather than traditional formal routes. Reynolds (2014) demonstrated that informal disposal routes outweigh formal methods by a factor of fifteen with respect of FW disposal in Australian households. This indicates that formal FWT systems have less perceived benefit to ordinary households from both a convenience and cost-benefit perspective. HFW treatment has become a pressing issue that encompasses both the technical and environmental challenges of efficient disposal and resource recovery, the solutions for which will require careful consideration of the underlying socio-economic, governance and consumer variables that ultimately decide the success of any MCE based interventions. In addition, most studies in comparing technologies and management systems have not used first-hand or punctual data and some omit reference sources, which makes it difficult to trace the analysis to the original source. In particular when it comes to sensitive information, the data collected is not always reliable. The operators of waste treatment facilities often do not disclose such data unless under legal obligation, which normally is not the case (Massarutto, 2015).

Massarutto (2015) stated that the costs in FW treatment facilities may vary by up to 80% and may include different timeframes and economic condition. Given the distinct urbanisation style of Australia (Spencer et al., 2015), systematic and scientifically-based research of HFW management and development of relevant technology in Australia has become an urgent matter.

3.5 Conclusion

Notwithstanding that special cases require special treatments, policies or programs for reducing FW implemented by different countries can be useful as a reference while formulating and developing our own. This project aims at seeking optimal solutions to HFW management for Greater Melbourne and may be applicable to other urban areas.

3.6 References

Adhikari, BT, A; Martinez, J; Barrington, S 2010, 'Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada', *Waste Management & Research*, vol. 28, no. 11, pp. 1039-53.

Annepu, RK 2012, 'Sustainable SolidWaste Management in India', Master of Science thesis, Columbia University.

Australian Government Department of the Environment 2013, *National waste reporting 2013*, Canberra, ACT, viewed 03/2015, <https://www.environment.gov.au/resource/national-waste-reporting-downloads>.

Bernstad, A 2012, 'Household food waste management–Evaluations of current status and potential improvements using life-cycle assessment methodology', Lund University.

Chen, X, Geng, Y & Fujita, T 2010, 'An overview of municipal solid waste management in China', *Waste Management*, vol. 30, no. 4, pp. 716-24.

Cheng, HH, Yuanan 2010, 'Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China', *Bioresource Technology*, vol. 101, no. 11, pp. 3816-24.

Dung, TNB, Sen, B, Chen, C-C, Kumar, G & Lin, C-Y 2014, 'Food Waste to Bioenergy via Anaerobic Processes', *Energy Procedia*, vol. 61, pp. 307-12.

Eunomia research & consulting 2007, *Managing Biowastes from Households in the UK: Applying Life-cycle Thinking in the Framework of Cost-benefit Analysis*, WRAP, Bristol BS1 4HW, <www.wrap.org.uk/sites/files/wrap/Biowaste_CBA_Final_Report_May_2007>.

European Commission 2011, *Preparatory Study on Food Waste Across Eu 27*.

—— 2015, *Generation of waste by households activities, by waste category and hazardousness (2012)*, viewed 12/08 2015, <http://ec.europa.eu/eurostat/tgm/refreshTableAction.do>.

Feo, GD & Malvano, C 2009, 'The use of LCA in selecting the best MSW management system', *Waste Management*, vol. 29, no. 6, pp. 1901-15.

Hong, RJW, G. F.; Guo, R. Z.; Cheng, X.; Liu, Q.; Zhang, P. J.; Qian, G. R. 2006, 'Life cycle assessment of BMT-based integrated municipal solid waste management: Case study in Pudong, China', *Resources, Conservation and Recycling*, vol. 49, no. 2, pp. 129-46.

Inaba, RN, Keisuke; Fujii, Minoru; Hashimoto, Seiji 2010, 'Hybrid life-cycle assessment (LCA) of CO2 emission with management alternatives for household food wastes in Japan', *Waste Management & Research*, vol. 28, no. 6, pp. 496-507.

Jackson, MA 1975, *Principles of Program Design*, Academic Press, Inc.

Knipe, AD 2006, 'The management of household food waste – summary ‘should composting begin at; home?', *Local Authority Waste and Recycling*.

Lamb, GF, L 2010, 'An investigation into food waste management'.

Levis, JWB, M A; Themelis, N J; Ulloa, P 2010, 'Assessment of the state of food waste treatment in the United States and Canada', *Waste Management*, vol. 30, no. 8, pp. 1486-94.

Lombardi, LC, Ennio; Corti, Andrea 2015, 'A review of technologies and performances of thermal treatment systems for energy recovery from waste', *Waste Management*, vol. 37, pp. 26-44.

Mason, LB, T; Fyfe, J; Smith, T; Cordell, D 2011, *National food waste assessment-final report*, Institute for Sustainable Futures, UTS.

Massarutto, A 2015, 'Economic aspects of thermal treatment of solid waste in a sustainable WM system', *Waste Management*, vol. 37, pp. 45-57.

Matsuda, TY, Junya; Hirai, Yasuhiro; Sakai, Shin-ichi 2012, 'Life-cycle greenhouse gas inventory analysis of household waste management and food waste reduction activities in Kyoto, Japan', *The International Journal of Life Cycle Assessment*, vol. 17, no. 6, pp. 743-52.

Melikoglu, M, Lin, C & Webb, C 2013, 'Analysing global food waste problem: pinpointing the facts and estimating the energy content', *Open Engineering*, vol. 3, no. 2, p. 157.

Modak, PW, Vera; Gueye, Moustapha Kamal 2011, *Waste - Investing in energy and resource effciency*, UNEP, <http://www.unep.org/greeneconomy/Portals/88/ >.

Monier, VM, S; Escalon, V; O'Connor, Clementine; Anderson, Gina; Montoux, Hortense; Reisinger, Hubert; Dolley, Phil; Ogilvie, Steve; Morton, Gareth 2010, *Bio food waste - final report*, Euopean Commission.

Nixon, JD, Dey, PK, Ghosh, SK & Davies, PA 2013, 'Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process', *Energy*, vol. 59, pp. 215-23.

Oxford Dictionaries n.d., *Developing country*, Oxford University Press <http://www.oxforddictionaries.com>

Posmanik, R, Labatut, RA, Kim, AH, Usack, JG, Tester, JW & Angenent, LT 2017, 'Coupling hydrothermal liquefaction and anaerobic digestion for energy valorization from model biomass feedstocks', *Bioresource Technology*, vol. 233, pp. 134-43.

Randell, P, Pickin, J & Grant, B 2014, *Waste generation and resource recovery in Australia. Reporting period 2010-2011* prepared for Department of Sustainability, Environment, Water, Population and Communities.

Recycled Organics Unit 2006, *Organics Recycling in Australia: Industry Statistics 2006*, Recycled Organics Unit, Sydney, <www.recycledorganics.com/publications>.

—— 2007, *Organics Recycling in Australia: Industry Statistics 2007*, Recycled Organics Unit, Sydney, <www.recycledorganics.com/publications>.

—— 2008, *Organics Recycling in Australia: Industry Statistics 2008*, Recycled Organics Unit, Sydney, <www.recycledorganics.com/publiations>.

—— 2009, *Organics Recycling in Australia: Industry Statistics 2009*, Recycled Organics Unit, <www.recycledorganics.com/publiations>.

—— 2010, *Organics Recycling in Australia: Industry Statistics 2010*, Recycled Organics Unit, Sydney, <www.recycledorganics.com/publiations>.

—— 2011, *Organics Recycling in Australia: Industry Statistics 2011*, Recycled Organics Unit,, Sydney, <www.recycledorganics.com/publications>.

Reynolds, CM, V; Davison, S; Hoj, SB; Vlaholias, E; Sharp, A; Thompson, K; Ward, P; Coveney, J; Piantadosi, J; Boland, J; Dawson, D 2014, 'Estimating informal household food waste in developed countries: the case of Australia', *Waste Management Research*, vol. 32, no. 12 pp. 1254-8.

Righi, S, Oliviero, L, Pedrini, M, Buscaroli, A & Della Casa, C 2013, 'Life Cycle Assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches', *Journal of Cleaner Production*, vol. 44, pp. 8-17.

Rousta, K, Richards, T & Taherzadeh, MJ 2015, 'An Overview of Solid Waste Management toward Zero Landfill: A Swedish Model', in MJ Taherzadeh & T Richards (eds), *Resource Recovery to Approach Zero Municipal Waste*, CRC Press, NY.

Song, GL, Mingjing; Semakula, Henry Musoke; Zhang, Shushen 2015, 'Food consumption and waste and the embedded carbon, water and ecological footprints of households in China', *Science of The Total Environment*, vol. 529, pp. 191-7.

Spencer, A, Gill, J & Schmahmann, L 2015, 'Urban or suburban? Examining the density of Australian cities in a global context', paper presented to State of Australian Cities Conference 2015.

S Victoria 2015, *Victoria local government annual survey 2012-2013*, by Sustainability Victoria, Sustainability Victoria.

Takata, M, Fukushima, K, Kino-Kimata, N, Nagao, N, Niwa, C & Toda, T 2012, 'The effects of recycling loops in food waste management in Japan: Based on the environmental and economic evaluation of food recycling', *Science of The Total Environment*, vol. 432, pp. 309-17.

A Government 2008, *National Greenhouse and Energy Reporting (Measurement) Determination 2008*, by The Office of Parliamentary Counsel, <https://www.comlaw.gov.au/Details>.

The World Bank n.d., *About Development*, The World Bank, viewed 22nd of October, 2015, <http://web.worldbank.org/WBSITE/EXTERNAL/EXTSITETOOLS/0,, >.

Thi, N-B-D, Kumar, G & Lin, C-Y 2015, 'An overview of food waste management in developing countries: Current status and future perspective', *J Environ Manage*, vol. 157, pp. 220-9.

Transpacific Industries Group Ltd n.d., *Australian waste: the facts*, <http://www.transpacific.com.au>.

EPA 2016, *Advancing sustainable materials management: 2014 fact sheet*, by USAEPA.

Wen, Z, Wang, Y & De Clercq, D 2016, 'What is the true value of food waste? A case study of technology integration in urban food waste treatment in Suzhou City, China', *Journal of Cleaner Production*, vol. 118, pp. 88-96.

Xu, F, Li, Y, Ge, X, Yang, L & Li, Y 2018, 'Anaerobic digestion of food waste – Challenges and opportunities', *Bioresource Technology*, vol. 247, pp. 1047-58.

Yu, LY, Kuang; Ningsheng, Huang; Zhifeng, Wu; Lianzhong, Xu 2008, 'Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation', *Renewable Energy*, vol. 33, no. 9, pp. 2027-35.

Zhang, C, Su, H, Baeyens, J & Tan, T 2014, 'Reviewing the anaerobic digestion of food waste for biogas production', *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 383-92.

Zhang, DQT, Soon Keat; Gersberg, Richard M. 2010, 'Municipal solid waste management in China: Status, problems and challenges', *J Environ Manage*, vol. 91, no. 8, pp. 1623-33.

Zschokke, M, Kagi, T & Dinkel, F 2012, 'Comparing environmental impacts of end-of-life treatments of food waste', in *LCA Food Conference*, Saint-Malo.

SA Government 2010, *Valuing our food waste South Australia's household food; waste recycling pilot summary report*, by ZWSA.

Chapter 4: Household food waste management in Greater Melbourne - an analysis of the current approaches of three selected Councils via targeted enquirers

4.1 Introduction

The Victorian State Government's urban planning scheme forecasts that household density will continue to increase, especially in the inner and western suburbs. As waste audits conducted by the Metropolitan Waste and Resource Recovery Group (MWRRG) illustrate (Melbourne city council, 2018a), household food waste (HFW) makes up 47 – 50% of a garbage bin, by weight. Information is also available showing that, in Victoria, 97% of those HFW is sent to landfill (Victorian Government, 2013). Finding ways to help householders reduce food waste offers significant opportunities to lower the quantity of waste delivered to landfill, which would also reduce household expenditure relating to avoidable food waste.

The question of whether different types of accommodation/dwelling influence the quantity or composition of food waste is an important factor to consider when analysing domestic food waste management issues. The influence of relative accommodation type has not, to our knowledge, been previously analysed in detail. Greater Melbourne provides an ideal setting for such an analysis. Therefore, this work has adopted a case study approach through a survey methodology investigating three regions of Greater Melbourne, namely the Cities of Wyndham, Yarra and Melbourne. These three regions have been chosen to be representative of (i) traditional free-standing house accommodation (ii) semi-detached/low-to-medium-rise apartment accommodation and (iii) high-rise accommodation, respectively. In this context it was also considered worthwhile to explore the economic and social factors that impinge upon domestic food waste disposal and to identify and compare the pros and the cons of current existing technologies, within a micro-circular-economic (MCE) framework. These factors will be described in more detail in Chapter 2, Section 6 - and later in this chapter. The methodology will include accessing and reviewing the audit reports of these councils, interviewing selected Council employees and obtaining questionnaire (survey) data from residents across the different accommodation types. This work is being undertaken to inform the choice of optimum technologies and management systems for dealing with household FW that will benefit both the environment and the economy.

4.2 Framework

4.2.1 The "targeted enquiry"

It was considered desirable to obtain some general information from the three Councils in relation to their management of food waste. This was carried out by an analysis of their relevant released reports, by personally meeting and discussing this area with selected council staff, particularly the team leaders and by obtaining a summarized response to a brief questionnaire ("semi-structured interview"), Figure 4.1, that was summarized and collated by each Council management team leader.

4.2.2 Definitions

Special terminology has developed in the waste management industry and associated research. This terminology has, previously, not been well articulated due to the dissimilarity of methodologies, sample size, geographical location and household characteristics (EnviroCom Australia, 2014, Sibrian et al., 2016). Therefore, some specific terms are delineated as below:

Household: A **household** in this paper describes those living in one dwelling as a family, with or without children, or as a lone person or as a group of people.

Accommodation type: Due to the unequal distribution of land use in Australia, population density does not accurately indicate the true residential population. Even the terms low, medium and high density, that are often used to describe housing developments, do not have a nationally accepted standard and vary between cities and within cities (Environment and Sustainable Development, 2011). In Victoria, 95% of Greater Melbourne's population live in 17% of the total metropolitan area (Spencer et al., 2015). Therefore, the average "population density" and "household density" will be problematic in giving an accurate picture of 'residential density'. In Australia, traditional principle residential areas were commonly established in suburban areas where detached housing was the standard accommodation. The housing density in Australia varies from a low of between 8 - 15 dwellings/hectare to a medium of 30 - 40 dwellings/hectare[7]. The increase in population and the resulting influence on urbanisation has resulted in more semi-attached/attached and multi-unit/apartment housing. Therefore, to avoid confusion, we have used "accommodation type" in this paper which is used by the Wyndham council (.id., 2016). The categories of accommodation will be based on the density of the dwelling types in the residential areas.

The definitions of the **accommodation types**, as described in (i) to (iii) above may be further refined as follows:

(i) "Traditional" free-standing house accommodation/low density (LD) – i.e. a separate house; includes all free-standing dwellings separated from neighbouring dwellings by a gap of at least half a metre (for sample picture see Figure 5.6, Chapter 5).

(ii) Low-to-medium rise apartment accommodation - medium density (MD) includes all semi-detached, row, terrace or townhouses and flats in a one to seven storey block (for sample picture see Figure 5.5, Chapter 5).

(iii) High-rise accommodation - high density (HD) includes all flats/apartments in a greater than seven or more storey block (for sample picture see Figure 5.4, Chapter 5).

Garbage stream (GS): The waste generated daily in households that is not accepted in recycling bins.

Recycling stream (RS): As the Australian Waste Database (AWD) has classified: material that can be recycled including items such as glass, plastic and liquid paper board bottles, jars and containers; aluminium and steel cans, aerosols and foil; paper products.

Contamination: Any material placed in the recycling stream that should be put into the garbage stream.

Organic waste: Food waste and garden waste generated from a household.

[7] https://en.wikipedia.org/wiki/Medium-density_housing

4.3 Methodology

Broadly, this study is divided into two parts - Part 1: An analysis of a Council's waste management system reviews, which involve a Council's department of waste management and waste treatment contractors; and Part 2: Surveys of residents from three selected cities in the metropolitan area of Victoria, Australia.

There are different HFW waste management systems with different councils and even within different residential areas of one council, as determined by local economic considerations and technical resources (Giusti, 2009). However, despite such limitations of classification, overall HFW management systems can still be classified into two groups/lines: centralized and non-centralized (on-site), see Figure 2.3.

A Council's waste management system is set up along centralized lines, as indicated in Figure 2.3. HFW are collected in households' internal kitchen bins (KBs), then stocked in households' external garbage bins (GBs) for the weekly collection by a council contractor. The waste is then sorted or separated in a rubbish transit station. The non-recyclable waste, which is mostly organic, is then transferred to various waste treatment facilities including Commercial Composting (CC), Commercial Anaerobic Digesting (CAD), Incineration Treatment (IT) or Landfill.

The review will provide a big picture of current residential FW management at the council level; identify opportunities for possible strategic and technical development - within a Micro Circular Economics framework - and at the same time, encourage council support for more detailed scrutiny and research.

Selection of councils

The metropolitan area of Victoria is also referred to as "Greater Melbourne". According to the Australian Bureau of Statistics (ABS), Greater Melbourne makes up nearly 20% of Australia's population and 75% of Victoria's population. In the last ten years, it has witnessed the largest national growth rate of 2.1% (Glenn, 2016, Australian Bureau of Statistics, 2012 #892). Greater Melbourne includes 31 cities and 79 suburbs. To represent metropolitan Victoria in this case study, we have selected three cities that represent, although not exclusively, three types of accommodation type. The three cities are: the City of Melbourne - the center of the metropolitan area; the City of Yarra - one of the highest density inner-suburbs of Victoria, and the City of Wyndham - one of the highest growth outer suburbs. The population growth rate of the City of Melbourne, the City of Yarra and the City of Wyndham are ~ 7%, 4% and 6%, respectively.

Auditing of report reviews and authorities' semi-structured interviews

The three selected councils were approached, and their Waste Management Auditing Reports were collected for review and analysing.

The authorities' semi-structured interviews covered four topics, namely, management systems, data sources, treatment technologies and plans for the future. The interview question sheet is shown in Figure 4.1.

4.4 Background information for the three selected Victorian local government areas (Cities)

4.4.1 The City of Melbourne

Demography

Melbourne city, covering 36.2 km^2, is the capital of Victoria and the second largest city in Australia. It is a centre for administrative, business, and cultural activities in Victoria. The City of Melbourne council has fifteen suburbs, Map 4.1. The principle residential areas are the CBD, Carlton, North Melbourne and Southbank, Table 4.1[8]. It has been selected five times as the "world's most liveable city" by the Economist Intelligence Unit[9].

[8] http://www.melbourne.vic.gov.au/about-melbourne/melbourne-profile/suburbs/Pages/suburbs.aspx

[9] http://www.theage.com.au/victoria/melbourne-named-worlds-most-liveable-city-for-fifth-year-running-20150818-gj1he8.html

COUNCIL/CONTRACTOR INTERVIEW QUESTIONNAIRE

(Note: Not all questions will be relevant to your council. Please answer as best as you can / your knowledge.)

Section A. About food waste data sources:

1. What kind of organic waste data do you have?

____

2. Who collected/collects the data??

____

3. How is data relevant to food waste collected?

____

4. Does such data relate to specific kinds of communities or dwelling types or are they averaged / aggregated? If answer is "Yes", could you please provide the data or source?

____

5. Is such data publicly available?

____

6. Are there any gaps in food waste data for your council? If answer is "Yes", could you please provide the data or source?

____

7. Are there any figures for the last (say) 15 years and projections for the next (say) 15 years? If answer is "Yes", could you please provide the data or source?

____

8. What are the resident densities that relevant to those figures?

____

Section B. Food waste management:

1. Who is responsible for garbage collection and treatment?

____

2. What kind of collection system is used in your shire?

____

3. How many garbage transporting /sorting stations are there within your shire?

____

4. What percentage of garbage, after sorting, is sent to landfill in your shire?

____

5. What are the costs involved in managing such waste?

____

6. What proportion of the council rates does this constitute?

____

Section C. Food waste treatment methods / technology:

1. What percentage of food waste is composted with listed treatment methods?

Centralised:____________________________

Home based:____________________________

2. What percentage of food waste is treated using anaerobic digestion technology in your shire?

Centralised:____________________________

Home based:____________________________

3. What are the important issues when choosing a treatment technology?

(Please rank these issues in order of importance.)

____

Section D. Questions of relevance to food waste management:

1. What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?

____

2. What are the barrier to the implementation of a "toward zero waste" policy?

____

3. Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?

____

4. Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?

____

5. Would the council be willing to subsidize the participation of residents in project designed to advance the management of household food waste?

____

THANK YOU FOR TAKING THIS INTERVIEW WITH US:

Would you permit me to follow-up and clarify some of the responses you provided in this survey?

If yes, please provide some of your details below.

Name: ____________________________

Council:____________________________

Position: ____________________________

Email:____________________________

Telephone: __________Mobile: ___________

Preferred way to contact you: _____________

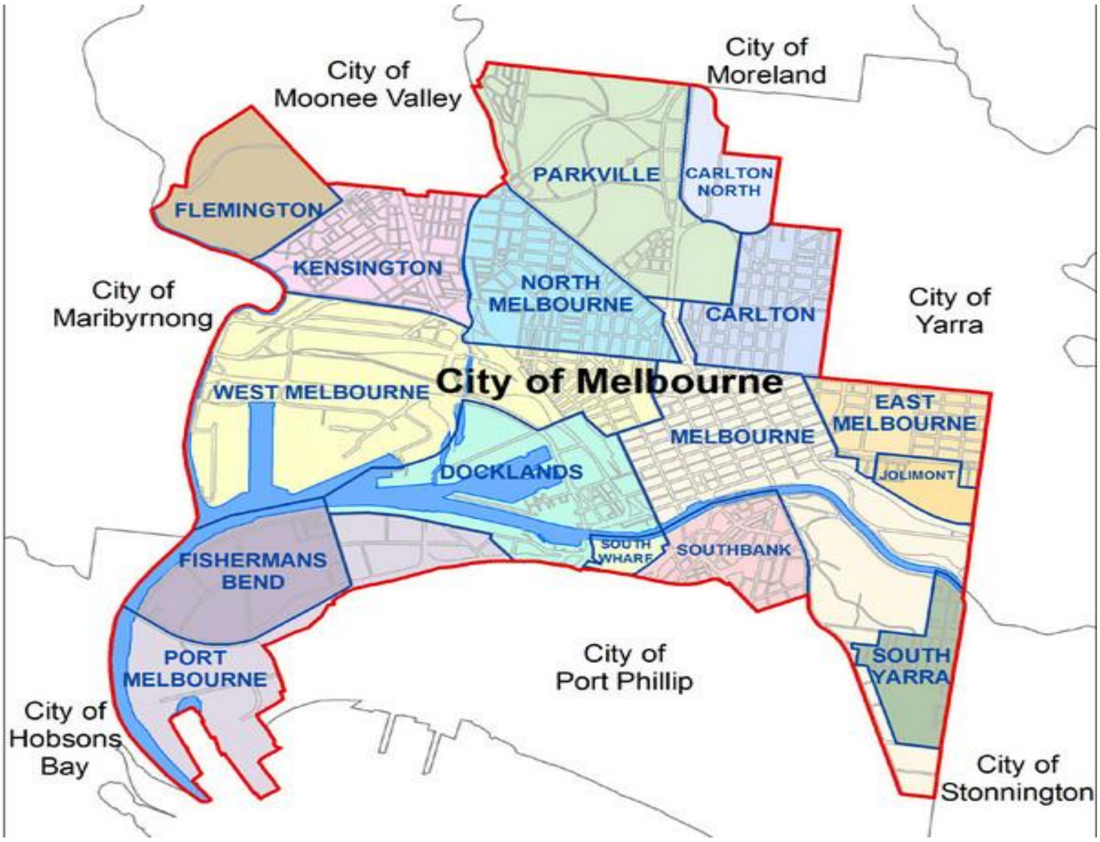
Figure 4.1 Authorities semi-structured interview question sheet

The residential population in the City of Melbourne has been experiencing a dramatic increase in population. It is the largest growth capital city in Australia. The population number increased 42% from 2004 to 2014 which is an annual rate of 4.6%. In the next twenty years, from 2016 to 2036, it is predicted that the population of Melbourne will continue to growth by 58.91% according to expert predictions (.id the population experts, 2017). Within the population structure, the 25 - 45 age groups has the largest proportion with a figure of 46.5% compared to the total population (Melbourne city council, 2018b).

Current household food waste management within the city

Over 70% of the population of the City of Melbourne live in high-rise buildings (Melbourne, 2005, Melbourne city council, 2017c). Its waste management system has been adapted to accommodate some unique challenges. Household garbage increased 33% during 2009 -2015 with expenditure at an average of $9.8 million each year on waste services (Melbourne city council, 2015a). However, due to the housing boom in the City of Melbourne, the environmental performance of many, if not most, new high-rise buildings has been left behind (James, 2015Melbourne, 2015 #885, Melbourne city council, 2015a). Surveys undertaken from residents who live in new high-density apartments have been of considerable help in the formulation of future policies and development regulations in 2013. The surveys' results showed that food waste comprises over 40% of the average household garbage bin, and only in newer buildings was there a drop off recycling bins for paper, cardboard and other mixed recyclable materials (Melbourne city council, 2017b, Melbourne city council, 2017c). The research done by James (2015) also indicated that the condition of emission and waste management for Melbourne has reached a "critical" level, Figure 4.2. Therefore, a new study is considered to be essential in order to identify barriers and assist in developing the best solutions.

Map 4.1 City of Melbourne and its localities



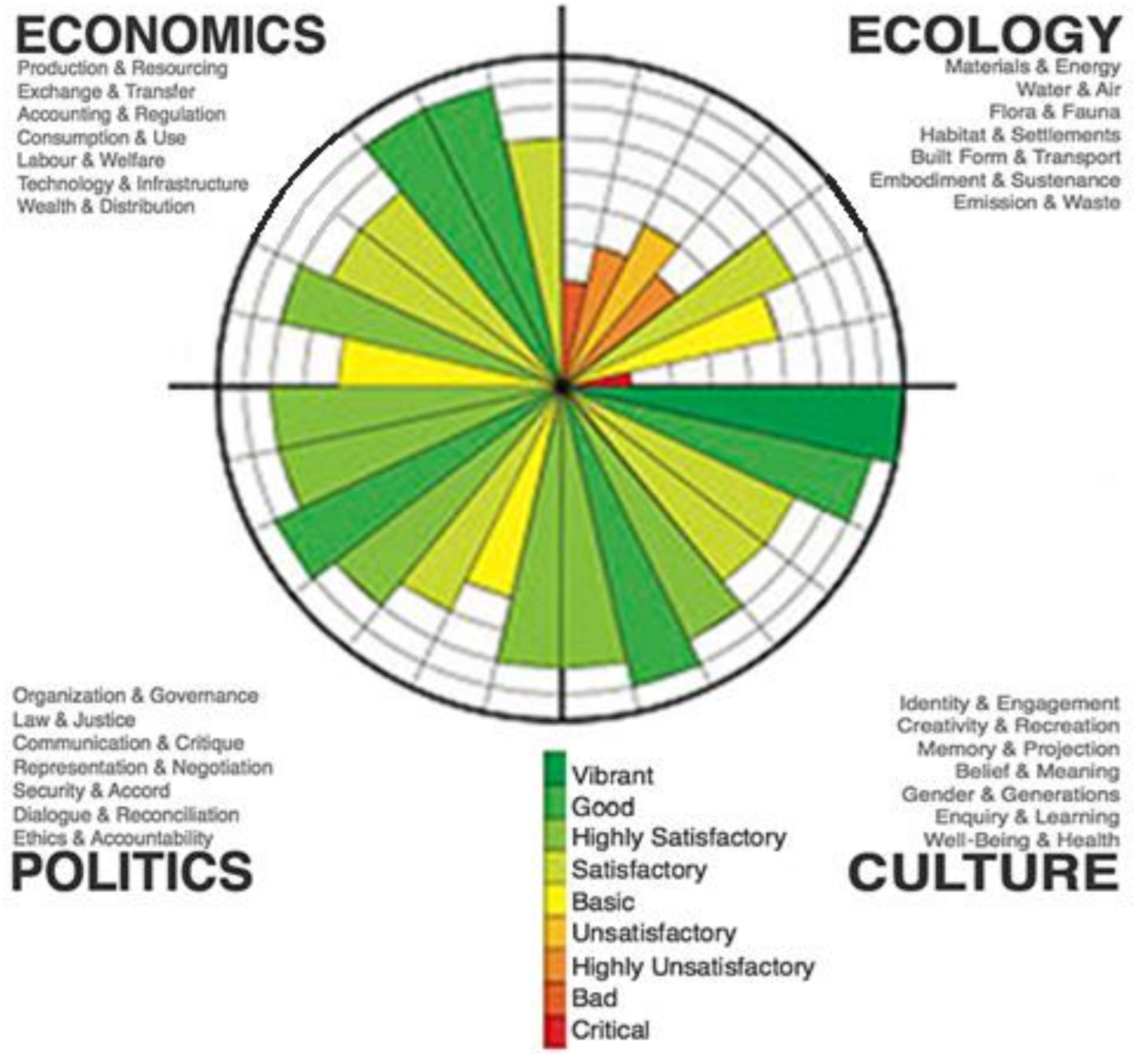


Figure 4.2 Circles of sustainability in Melbourne (James, 2015).

Table 4.1 Past, current and projected population and household change in urban area of City of Melbourne (.id.)

Localities Area (postcode)		2016	2036 (prediction)	Total change (2016-2036)	% of change (2016-2036)
City of Melbourne	Number of people	133,388	211,962	78,574	58.91
	Number of households	63,100	93,269	30,169	47.81
CBD (3000, 3001 & 3004)	Number of people	35,159	52,324	17,165	48.82
	Number of households	17,853	27,532	9,679	54.22
Carlton (3053)	Number of people	19,296	28,381	9,085	47.1
	Number of households	9,421	14,335	4,914	52.16
Docklands (3008)	Number of people	10,558	17,299	6,741	63.85
	Number of households	5,346	9,081	3,735	69.87
East Melbourne (3002)	Number of people	5,339	6,355	1,016	19.03
	Number of households	2,735	3,314	579	21.17
Kensington (3031)	Number of people	10,922	14,966	4,044	37.03
	Number of households	4,964	7,054	2,090	42.1
North Melbourne (3051)	Number of people	14,193	28,311	14,118	99.47
	Number of households	6,026	12,678	6,652	110.39
Parkville (3052)	Number of people	8,195	8,129	-66	-0.8
	Number of households	2,347	2,414	67	2.86
Southbank (3006)	Number of people	17,821	32,262	14,441	81.03
	Number of households	8,827	16,103	7,276	82.43
South Yarra (3141)	Number of people	6,667	7,246	579	8.69
	Number of households	3,404	3,764	360	10.58
West Melbourne (3003)	Number of people	5,240	16,696	11,456	218.63
	Number of households	2,179	7,342	5,163	236.94

4.4.2 City of Yarra

Demography

The City of Yarra is a north-eastern suburb of Greater Melbourne and has a common boundary with the City of Melbourne. It is the smallest inner "city", being 1,953 hectares in area and divided into 10 suburbs, Map 4.2. The population was 88,120 in 2016 with an annual growth rate of 2.21% over the last five years. The projected growth of population and households for the next twenty years (2016-2036) is estimated to be 32.81 % and 35.56% respectively, Table 4.2 (.ID., 2013).

The council's community profile indicated that 29% of the residents of Yarra are born overseas. The largest age group is 25-34 (29 %) following by 35 – 44 (16.7 %). Couples without dependents and lone person households are common household types in Yarra and are 26.9 - 26.7 % and 31.2 - 32.3%, respectively (.ID., 2013). Over 70.41% of the population who are over 15 years old have post schooling qualifications (.id., 2011). It has a high education and income level for individuals and a lower unemployment rate of 3.1%, compared with national figures, with relatively fewer low income individuals (ABS, 2010, .id., 2016).

Current household food waste management in the City of Yarra

Household food waste has been collected as part of the general garbage as a comprehensive service provided by council. The contractors have implemented the services weekly through a kerbside collection system. For LD housing each household has one 80 litre mobile garbage bin and one 120 litre recycling bin. For HD housing each building has 80 to 660 litre mobile garbage bins and 120 to 1,100 litre recycling bins, depending on the numbers of units in the building.

As an accredited Gold Waste Wise City, Yarra had also developed some other waste management plans such as Compost Bins and Worm Farms, Household Waste and Recycling etc. (City of Yarra, 2016). The City of Yarra also has a target, as stipulated in the 2013 plan, of reducing by 20%, the proportion of household waste sent to landfill by 2020 (Yarra city council, 2013). It is also targeting "net zero" GHG emissions by 2020 Yarra city council (2013). By achieving these targets, the council has introduced a series of programs from four "pathways" named: Community Empowerment and Local Action, Urban Ecology and Natural Environment, Sustainable City Infrastructure and Lifestyles, and Sustainable Council Operations. The main goal with all of these pathways is to encourage residents and organisations to take part in the activities of best waste management practices and sustainable living lifestyles.

Map 4.2 City of Yarra and the localities (.ID., 2013)

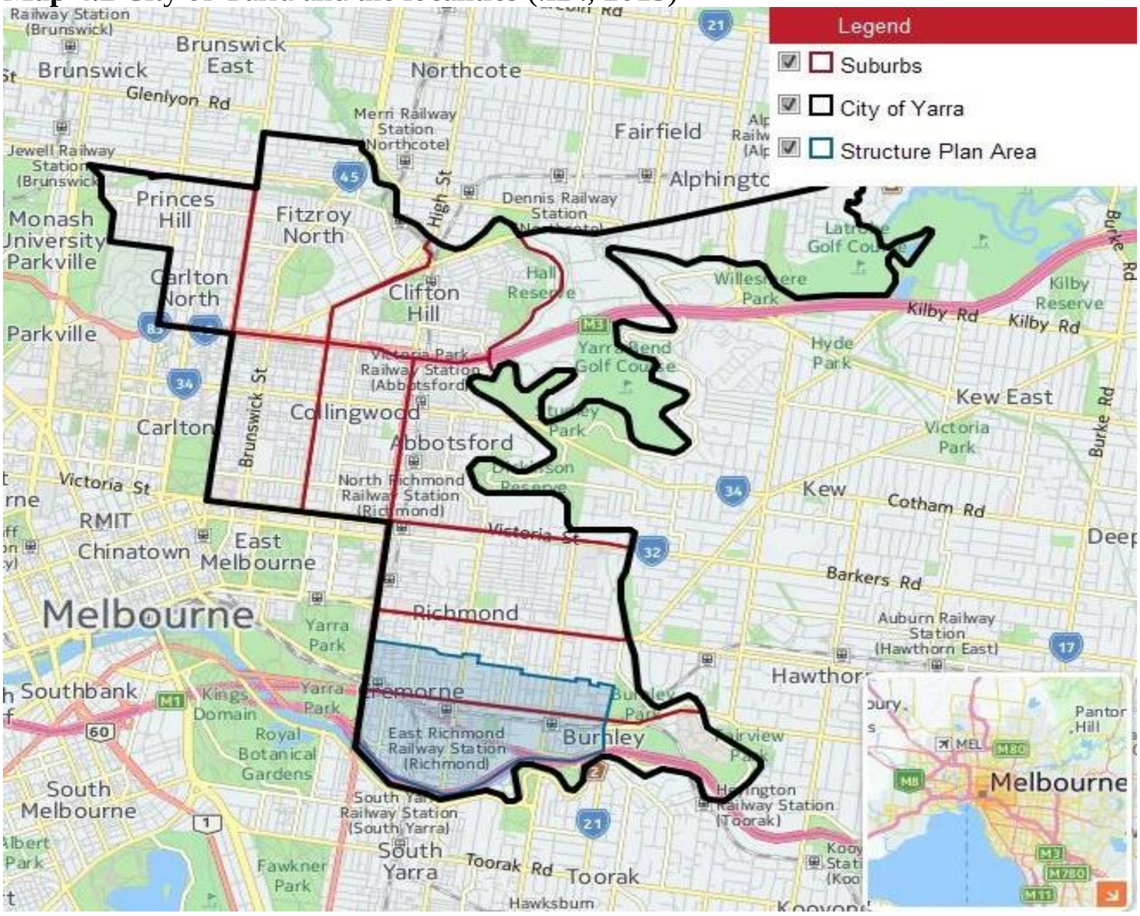


Table 4.2 Past, current and projected population and household change in urban area of City of Yarra (.ID., 2013)

Localities Area (postcode) (person/ per hectare)		2016	2036 (prediction)	Total change (2016-2036)	% of change (2016-2036)
City of Yarra (49.15)	**Number of people**	**88,120**	**117,036**	**28,916**	**32.81**
	Number of household	**39,431**	**53,452**	**14,021**	**35.56**
Abbotsford (3067) (24.49 – 58.84)	Number of people	8,229	11,768	3,539	43.01
	Number of household	3,388	5,077	1,689	49.85
Carlton North (3054) (52.48 - 57)	Number of people	8,771	9,006	235	2.68
	Number of household	3,892	4,053	161	4.14
Central Richmond (3121) (52.22 – 74.65)	Number of people	13,595	16,423	2,828	20.8
	Number of household	6,478	7,934	1,456	22.48
Clifton Hill (3068) (30.79 – 35.13)	Number of people	6,303	6,605	302	4.79
	Number of household	2,729	2,919	190	6.92
Collingwood (3066) (44.66 – 80.02)	Number of people	7,356	11,603	4,247	57.74
	Number of household	3,535	5,657	2,122	60.03
Richmond South (3121) (14.13 – 29.41)	Number of people	4,271	7,675	3,404	79.70
	Number of household	1,989	3,579	1,590	79.94
Fairfield (3078) (6.03 – 16.88)	Number of people	2,808	6,550	3,742	133.26
	Number of household	1,043	2,673	1,630	156.28
Fitzroy (3065) (59.88 – 79.96)	Number of people	10591	12,554	1,963	18.54
	Number of household	4,671	5,664	993	21.28
Fitzroy North (3068) (41.32 – 60.94)	Number of people	12,056	15,844	3,788	31.42
	Number of household	5,414	7,214	1,800	33.25
North Richmond (3121) (50.62 - 88)	Number of people	14,139	19,007	4,868	34.43
	Number of households	6,292	8,682	2,390	37.99

4.4.3 City of Wyndham

Demography

The City of Wyndham is located in the outer south-west of Melbourne. Its area covers 54,200 hectares with population of 209,750 people in 2016, Map 4.3. It is the largest growth area in Australia with 5.6% annual growth rate. The population has increased 96.2% during 2004 - 2014 (Wyndham city council, 2016a). In next twenty years, from 2016 to 2036, the population of Wyndham will continue to growth by average 83.21% according to expert projections (.id., 2016). The City of Wyndham has nine suburbs. It is a typical Victorian urban-to-rural transition area, Map 4.4. The population is concentrated in the Hoppers Crossing, Point Cook and Werribee areas, Table 4.3.

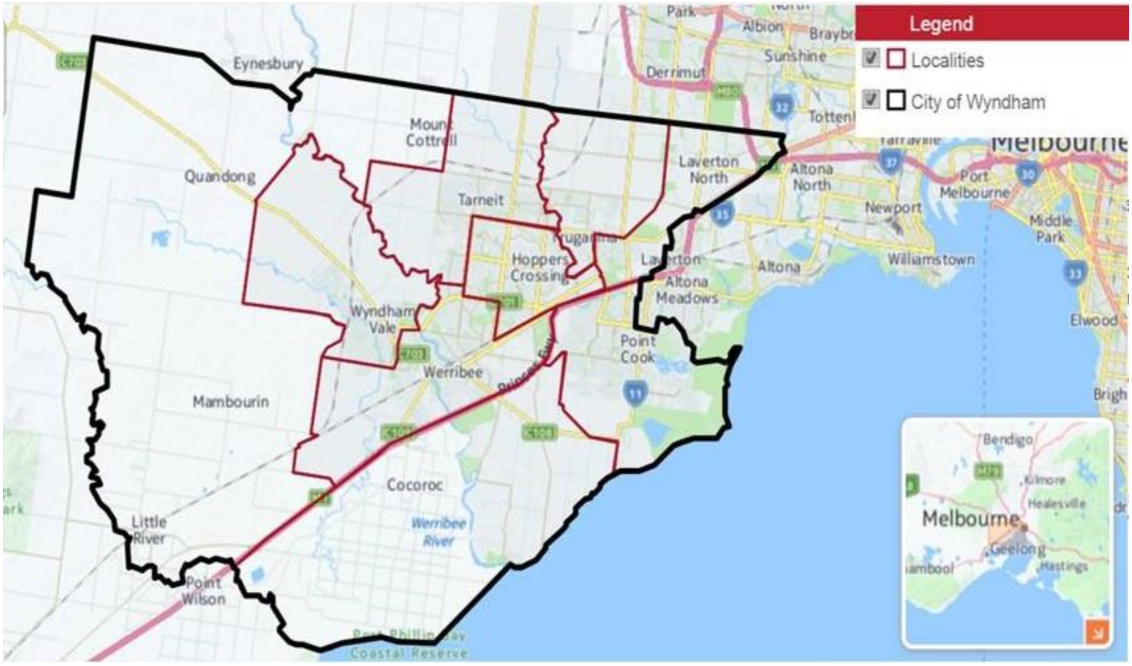
The "2011 Census" (.id., 2011) indicated that 49% of the residents of Wyndham are employed and 45% aged over 15 do not have post schooling qualifications. The largest age group is 35-49 (28%) following by 25 – 34 (22%). 34% of residents were born outside of Australia.

Current household food waste management of the city

In City of Wyndham, there are two waste collection systems: three-bin stream and two-bin stream. The three-bin includes Garbage-bin, Recycling-bin and Green-bin. The two-bin includes only Garbage-bin and Recycling-bin. The three-bin is an option that requires extra payment. There are only ~ 30% of households using this system (Wyndham city council, 2015).

The garbage bins contain ~ 46 % of food waste (Wyndham city council). All of this is sent to landfill. Given the projected population and household growth of 83.21 % and 86.86 % respectively in the next twenty years, the waste management target of reducing waste to landfill by 90% (Wyndham city council, 2015) will become extreme challenging.

Map 4.3 City of Wyndham and the localities (.id., 2016)



Map 4.4 Urban growth boundary of City of Wyndham (Wyndham city council, 2016b)

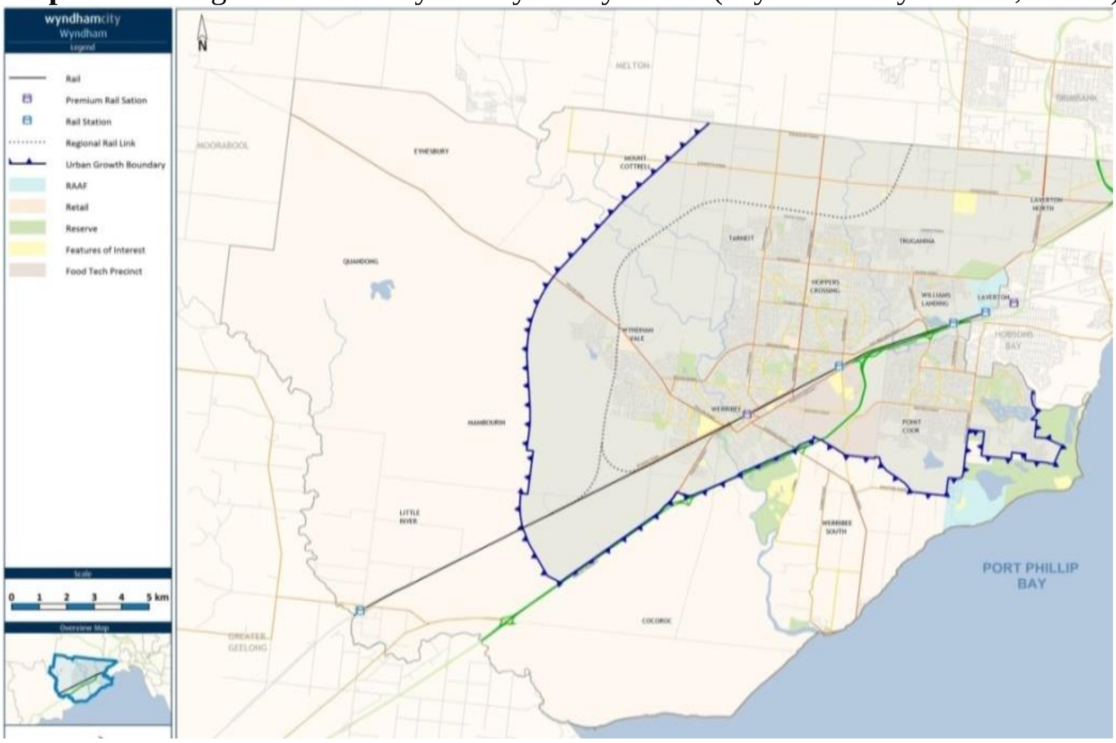


Table 4.3 Past, current and projected population and household change in urban area of City of Wyndham (.id.)

Localities Area (person/ per hectare)		2016	2036 (prediction)	Total change (2016-2036)	% of change (2016-2036)
City of Wyndham (4.45)	**Number of people**	209,750	384,275	**174,525**	**83.21**
	Number of Household	71,137	132,927	**61,790**	**86.86**
Hoppers Crossing (3029) (2.15 – 2.12)	Number of people	38,239	37,740	-499	-1.31
	Number of household	13,430	13,795	365	2.7
Little River (3211) (0.19 – 3.16)	Number of people	1,179	19,912	18,733	1,588.33
	Number of household	407	6,723	6,316	1,551.84
Point Cook (3030) (5.27 – 7.25)	Number of people	48,972	67,429	18,457	37.83
	Number of household	15,615	23,175	12,381	48.42
Tarneit (3029) (8.16 – 17.22)	Number of people	31,159	65,711	34,552	110.89
	Number of household	10,140	21,634	11,494	113.35
Truganina (3029) (3.29 – 6.54)	Number of people	18,402	36,627	18,225	99.04
	Number of household	5,648	11,888	6,240	110.48
Werribee (3030) (17.17 – 33.05)	Number of people	40,865	78,665	37,800	92.5
	Number of household	15,301	29,142	13,841	90.46
Cocoroc (3030) (0.53 – 2.27)	Number of people	2,312	9,986	7,674	331.92
	Number of household	825	3,416	2,591	314.06
Laverton North (3026) (3.85 – 6.31)	Number of people	5,770	9,458	3,688	63.92
	Number of household	1,901	3,354	1,453	76.43
Wyndham Vale (3024) (7.37 - 18.95)	Number of people	22,853	58,749	35,896	157.07
	Number of household	7,870	19,800	11,930	151.59

4.5 Reviews and interviews – Results

4.5.1 City of Melbourne

4.5.1.1 Authority reports

The environmental auditing report of the City of Melbourne was not available during this research project. However, some pertinent information from both the City of Melbourne Annual Report (2016-17) and the City of Melbourne Annual Report (2017-18) was available.

Thus, in last two financial years, from 2016 to 2018, the City of Melbourne has invested over 5 million Australia dollars in projects with environmental benefits to the City; through a council held investment management company named SMF Investment Management Pty Ltd. Notably, waste management service fees have increased 23.5% from $442,000 (year 2017) to $546,000 (year 2018). Based on this figure, the commitment towards meeting the operating costs for waste management is projected to be up to $36.2 million dollars over the next 3 years (Melbourne city council, 2018a).

It is evident that the council has developed and is (will be) delivering a series of programs, such as Zero Net Emissions by 2020 (Updated 2014), Waste and Resource Recovery Plan (2015–18), Melbourne Renewable Energy Project and Emissions Reduction Plan (2016–2021). The objectives of these programs are to increase recycling and reduce waste-to-landfill, in order to improve Melbourne's resilience to environmental impacts. With these programs, the city council has achieved an estimated 11.5% decrease in greenhouse gas emissions and a 5.7% decrease in waste-to-landfill disposal from the 2014–15 to the 2015–16 financial years (Melbourne city council, 2017a). The council's research shows that the number of residents aware of climate change risks increased by 10.7% compared to the previous year.

However, from 2016 to 2017, the municipal waste-to-landfill had increased by more than 21.6% (3,931,856 litres volume of waste being send to landfill over this period). This can be related to a 12.9 % increase in the average number of households serviced and to population growth in the City of Melbourne.

4.5.1.2 Authority semi-structured interviews – summary of responses

The responses to the interview questions are aggregated on a section-by-section basis as follows. The following should be read with reference to Figure 4.1. The actual response sheets are provided in Appendix 4.1.

Section A. Food waste data sources

In the City of Melbourne, the residents' waste collection service is carried out by contractors on a five-day/one-cycle basis. Waste data are provided by the contractor via an aggregation form to the relevant department of the council, although these are not available to the public. Notably, HFW data are not separated from the overall data. Currently, the council does not have any projections for food waste reduction over next 15 years.

Section B. Food waste management

Household waste is stored in the council provided garbage bins and collected by waste services contractors. The residents' wastes are then centralized in a transfer station (Dynon Road Waste and Recycling Centre) without being sorted and taken to the Wyndham City Council landfill site in Werribee.

The landfill levy has risen 57.9% from the 2010-11 financial year ($38.5/tonne) to the 2015-16 financial year ($60.5/tonne). The City of Melbourne Council's current expenditure on waste services is around $10M per annum including garbage and recycling collection, transportation and public place bin collections. The tipping fees are a further $3.5M, including approx. $1.8M for the landfill levy (Melbourne city council, 2015b).

Section C. Food waste treatment methods/technology

There are no data on HFW treatment method / technology both on centralised and home-based waste.

Section D. Questions of relevance to food waste management

1. *What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?*

In response to the state government's "toward zero waste policy", the City of Melbourne developed The Waste and Resource Recovery Plan (2015-18). Based on this plan, a series of activities have been implemented. Within these activities, the Degraves Street Recycling Facility was set up with the aim of proving the technology for future property developers/Owners Corporations. This is a trial program that presents an opportunity to capture high-rise residential FW within the immediate vicinity as part of an expansion of the facility. This trial residential FW processing technology is set up in two apartment buildings, one located in the central city and one outside the central city, at an estimated cost of $30,000. This facility started a 6-month trial in Year 1.

Also, the council designed and implemented a trial organic waste collection service utilising a third bin for grass clippings and food waste that targeted low rise residential areas. However, due to lack of availability of food/green waste processing sites, this trial will not occur until Year 3 of the plan[10]. Thus the establishment of trial programs will test the viability of food waste diversion in residential high rise dwellings (Melbourne city council, 2015b).

What are the barriers to the implementation of a "toward zero waste" policy?

According to the ABS 2011 Census, 61 per cent of households in the municipality are high-rise apartments. Therefore, the barriers to the implementation of a "toward zero waste" policy mostly relate to high-rise dwellings. In this regard, the data from the Waste and Resource Recovery Plan (2015-18) shows a 25% increase in the rate of total waste generation in spite of a 13% decline in residential waste generated *per household* over the same time period. The one major reason for this is due to the high turnover/transience caused by the residential living environment. For the high-rise occupants, it is more convenient to dispose of all the household waste into a garbage chute than to take recyclable material to a central recycling area - which is normally located in a car park or at basement level. Therefore, this remains as a significant barrier to improving recycling rates in the municipality (Melbourne city council, 2015b).

[10] There is still no available data from this trial.

Another way to reduce food waste in the residential garbage bin is to support residents to manage food waste at home.

The provision of food waste recycling is supported by residents. High rise residents are seeking a way of composting their waste and some low-rise residents have requested a third bin for organic waste (i.e. food waste and/or green garden clippings) waste. A three-bin system is only practical for residents living in low-rise housing due to logistical issues concerning the management of high-rise waste collection.

2. *Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?*

There is already a department of CoM who deal with such research collaborations.

4. *Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?*

City of Melbourne has given significant support with such a survey.

5. *Would the council be willing to subsidize the participation of residents in a project designed to advance the management of household food waste?*

The City of Melbourne would be developing their own responses to household food waste in 2019.

4.5.2 City of Yarra

4.5.2.1 Authority reports

The auditing reports of 2014 from the City of Yarra reviewed in this paper include: the City of Yarra Domestic Waste Stream Audit, Garbage & Recycling conducted by the company All Environmental Concepts and the Yarra City Council High Rise Waste Audits conducted by environmental consultants from Wastemin Pty Ltd. Both documents were provided to us by Yarra Council.

All Environmental Concepts (2014) used random sampling collection methodology to investigate the residents' waste stream via kerbside collection in five areas and five day from Monday to Friday of Yarra city. During the investigation period the residents' participation rates reached 88.3%. The audit by Yarra Valley council included waste collected from 300 garbage and 300 recycling bins which were collected from 300 detached house dwellings and 117 garbage and 91 recycling bins from 29 high-rise dwellings, All Environmental Concepts stated that the HD dwellings had generated more garbage than the LD with an average weight of 18.56 kg and 7.11 kg per week, respectively. The HFW was the largest component in the waste stream making up 45.5% of the total weight of the garbage bin and 3% of the total weight of the recycling waste stream. The garden waste was the smallest component in the GB by weight in detached house and even zero in high-rise dwelling.

All Environmental Concepts stated that within the HFW, 68% of total weight was vegetable, fruit and starch (compostable waste) and the rest was un-compostable waste such as bones, meat, fats and seafood shells. Also, in the recycling waste stream, an average of 15.6% of the total weight was garbage which contaminated the recycling bin; especially for HD, the garbage's percentage was up to 28.4% of the total weight (All Environmental Concepts, 2014). Therefore, some recycling bins had to be merged into the garbage waste stream.

Wastemin Pty Ltd (2014) also demonstrated that in high-rise of the ministry housing, FW was the highest composition in the garbage bin being over 42.1% of the total weight, and had higher compostable waste, which was up to 82.66 % of the total weight. Another 8.2 % of the total weight in the recycling waste stream was also FW. In a comparison, over the 9 years, from 2005 to 2014, the weight of garbage bins had increased from 13.39 kg to 18.58 kg per week in HD dwellings. The contamination rates in the recycling stream had also increased from 9.8% to 15.6% in HD dwellings (All Environmental Concepts, 2014).

4.5.2.2 Authority semi-structure interviews - responses

Section A. About food waste data sources:

The City of Yarra has collected data for the weight and volume of food and green waste via the waste audits of Yarra Municipal Kerbside waste. These data include different sectors of the community. However, these data are not available to the public.

Section B. Food waste management:

The company "Four Seasons" is responsible for the garbage collection and treatment for the City of Yarra. The waste management system includes two bins – 80L rubbish bin and 120L recycling bin, and a collection once a week for the local residents. After collection, the wastes are directly sent to a final disposal location, of which 60% by weight of the waste is sent to a landfill site.

Notably, the cost in managing these wastes is up to 30% of the council rates.

Section C. Food waste treatment methods/technology: Anaerobic digestion technology is not used in FW treatment for both centralised and home-based systems in Yarra. The City of Yarra has, however, organised a trial of FW home composting that involves 1% of the residents' FW. The important issues for choosing a treatment technology are "tested, doesn't create odour or leakage and not too far away".

Section D. Questions of relevance to food waste management

The City of Yarra implements "less waste more resources policy" instead of "no zero-waste policy". There is therefore no barrier to "no zero-waste policy".

The council is collaborating with our current HFW on-site treatment project. Also, they are willing to subsidize the participation of residents in any project designed to advance the management of household food waste if there is the benefit of environment and economic.

4.5.3 City of Wyndham

4.5.3.1 Authority reports

The audit report from (EnviroCom Australia, 2014) stated that FW composes 46.8% of the garbage stream composition. Three bin households have a higher percentage of FW than two bin households, at 48.4% and 43.44%, respectively.

4.5.3.2 Authority semi-structured interview - responses

Section A. About food waste data sources:

In the City of Wyndham, the residents' waste collection service is provided by contractors on a weekly basis. The waste data is derived from both measurements taken from the compost processor and the waste audit. The data from Compost Revolution indicates that the waste is mostly FW. But there is no any data relate to specific kinds of communities or dwelling types or are they averaged / aggregated. Some of the FW data can be gained via Wyndham's State of the Environment Report. All the data are relevant to 80,000 dwellings in the City of Wyndham.

There has been no comprehensive data information reported over the last 15 years in Werribee.

Section B. Food waste management:

Wyndham City and Waste Contractor JJ Richards are responsible for garbage collection and treatment. Garbage from residential homes are collected weekly and transferred to transporting/soring station than all of the residual waste (100%) is sent to landfill site.

It is estimated that multiple millions of dollars are spent on resident waste management. However, the proportion within the council rates cannot be disclosed.

Section C. Food waste treatment methods/technology:

Only 1% of the FW is treated through a centralised vessel aerobic composting facility. There is no anaerobic digestion technology using in the City of Wyndham.

Cost, accepted feedstock, maintenance, end market of product are the important issues when choosing a treatment technology.

Section D. Questions of relevance to food waste management

1. *What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?*

The City of Wyndham has developed and adopted a policy for Waste and Litter Strategies to encourage diversion and minimise waste in order to achieve the set-up goal to divert 90% of waste from Landfill by 2040. For this target council even created a number of initiatives including specific roles in Waste Strategy and Waste Education.

2. *What is the barrier to the implementation of a "toward zero waste" policy?*

For implementation " toward zero waste" policy, community feedback/support, councillor support, existing infrastructure, budget constraints are the issues that need to be considered and resolved.

3. *Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?*

No

4. *Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?*

The City of Wyndham has assisted with this survey.

5. *Would the council be willing to subsidize the participation of residents in project designed to advance the management of household food waste?*

The city council is subsidizing the Compost Revolution project designed to advance the management of household food waste.

4.6 Conclusions

By combining the auditing reports and the feedback from the semi-structured interviews of all three selected city councils, the following conclusions can be drawn:

- Due to logistical issues, a three-bin system is only practical for residents living in detached houses and some low-rise apartments with large green common areas. For all three selected cities, the residents' waste collection service has been done by a contractor on five days to seven days, one circle, basis - depending on the dwelling types.

- Currently, for high-rise occupants, it is more convenient to dispose of all household waste into a garbage chute than to take recyclables to a central recycling area. Therefore, separating the HFW from other waste before disposal, becomes and important issue for improving municipal waste management.

- Waste management services fees have increased 23.5% from 2017 to 2018. The cost in managing these waste streams has increased council rates by up to 30%. The landfill levy has risen 57.9% since the 2010/11 to 2015/16 financial years. Operating costs of waste disposal were up to $36.2M over that time period. Currently, the cost of garbage and recycling collection, transportation and public-place bin collections is around $10M per annum. However, this amount may increase sharply from 2019 due to domestic waste treatment costs increasing and some countries such China have baned the waste import.

- Since 2016 to 2017 the municipal waste-to-landfill has increased more than 21.6%; the weight of garbage bins had increased from 13.39 kg to 18.58 kg per week for HD. HD had generated more garbage than LD with average weights of 18.56 kgs and 7.11kgs each week, respectively; within the HFW, 68% of total weight was vegetable, fruit and starch while the higher compostable waste was up to 82.66 % of the total weight.

- Waste data was provided in aggregated form by the relevant department of the council. These are not publically available. Meanwhile there is no separation of the HFW data in these sources.

- Household waste is stored in council provided garbage bins and collected by a waste services contractor. The residents' wastes are centralized without being sorted then sent to landfill sites at outer suburbs for all three selected cities.

- All three councils have developed a number of wastes reducing programs. The objectives of these programs are to increase recycling and reduce waste-to-landfill in order to improve Melbourne's resilience to environmental impacts. Forecasts for ongoing housing density growth indicate that there are economically efficient opportunities for the introduction and implementation of waste reduction systems.

- The establishment of trial programs to test the viability of food waste diversion in residential high-rise dwellings will be required to quantify the costs and benefits of proposed initiatives.

- The provision of food waste recycling is supported by residents, this can also be clearly seen in the residential survey of the next chapter (Chapter 5).

- The City of Melbourne has provided significant support to our surveys. It will be developing its own response to household food waste in year 2019. The City of Yarra is keen to partner with Victoria University.

- The important issues for choosing a treatment technology are "tested, doesn't create odour or leakage and not too far away". Cost, feedstock, maintenance, end market of product is also important issues when choosing a treatment technology.

4.7 References

.id the population experts 2017, *2016 AUSTRALIAN CENSUS UPDATES*, 10 Easey St, Collingwood, Australia, <https://home.id.com.au/demographic-resources/australian-census-information/2016-census-data-updates/>.

.id. 2011, *City of Maribyrnong: 2011 Census results - community profile*.

—— 2013, *Population forecaste - City of Yarra*, <http://forecast.id.com.au/yarra/Population-households-dwellings?WebID=190>.

—— 2016, *Dwellings and development map -- City of Wyndham*, .id., <http://forecast.id.com.au/wyndham/dwellings-development-map>.

ABS 2010, *National regional profile -economy*, <http://www.abs.gov.au/AUSSTATS>.

All Environmental Concepts 2014, *City of Yarra Domestic Waste Stream Audit, Garbage & Recycling*, Yarra City Council.

City of Yarra 2016, *Waste Wise*, viewed 04/05 2016, <http://www.yarracity.vic.gov.au/>.

EnviroCom Australia 2014, *Domestic waste audit - Wyndham city council*, (A816999), PO Box 238, Hallam, VIC 3803, <vic@envirocom.com.au>.

Environment and Sustainable Development 2011, *Population and residential density in Canberra*, ACT Government.

Giusti, L 2009, 'A review of waste management practices and their impact on human health', *Waste Management*, vol. 29, no. 8, pp. 2227-39.

Glenn 2016, *Will Melbourne's population overtake Sydney? Maybe in…*, 2/5, .ID. , <http://blog.id.com.au/2016/population/australian-population/will-melbournes-population-overtake-sydney-maybe-in/>.

James, p 2015, *Urban Sustainability in Theory and Practice -- Circles of sustainability*, Routledge, 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN, viewed 18 May 2015, (Victoria University).

Melbourne city council 2015a, *Homes for People: Housing Strategy 2014-18* 978-1-74250-988-4.

Co Melbourne 2015b, *Waste and Resource Recovery Plan 2015-18*, by ——, Melbourne city council.

V Melbourne city council, Australia 2017a, *City of Melbourne Annual report 2016-2017*, , by ——, Melbourne city council, viewed 2019.

—— 2017b, *City of Melbourne Food Policy - infographic*, <http://www.melbourne.vic.gov.au>.

—— 2017c, *High-rise apartment recycling*, <http://www.melbourne.vic.gov.au/residents/

2018a, *City of Melbourne annual report 2017–2018*, by ——, Melbourne city council.

—— 2018b, *Future population*, 28/03/2018, <http://melbournepopulation.geografia.com.au>.

2005, *Waste Management Strategy*, by Melbourne, tco.

Sibrian, R, Komorowska, J & Mernies, J 2016, *Estimating houseld and institutional food wastage and losses- measuring food deprivation and food excess in the total population*, Food and Agriculture Organization of the United Nations.

Spencer, A, Gill, J & Schmahmann, L 2015, 'Urban or suburban? Examining the density of Australian cities in a global context', paper presented to State of Australian Cities Conference 2015.

State of Victorian Government 2013, Getting Full Value --The Victorian Waste and Resource Recovery Policy, by Victorian Government, Victorian Government,, <www.dse.vic.govau/waste>

Wastemin Pty Ltd 2014, *Yarra City Council High Rise Waste Audits*.

Co Wyndham 2015, Council ordinary meeting attachment No:1- Draft waste & litter strategy 2016-2020, by Wyndham city council, Wyndham city council, viewed 10/04/2016.

——2016a, Demographics & Population <http://www.wyndham.vic.gov.au/about>.

——2016b, Map of Wyndham City, viewed 04/2016, http://www.wyndham.vic.gov.au.

—— 2016c, *Wyndham City Recycling and Waste Services Guide*, 23, Wyndham City Cuncil, 2016, <http://www.wyndham.vic.gov.au/waste/kerbside_collections>.

2013, *Sustainability*. *Yarra environment strategy 2013-2017*, by Yarra city council, Yarra city council, <www.yarracity.vic.gov.au>.

Chapter 5: A broad survey approach – the influence of dwelling type on attitudes towards household food waste management

5.1 Introduction

The "Toward Zero Waste" concept has been adopted and implemented as part of government policy reform in many parts of the developed world and includes strategies such as 3R - Reuse, Recycle and Recovery; LCA - Life Cycle Assessment (Cherubini, 2009, Cherubini, 2011, Messina, 2012, Tonini and Astrup, 2013, Vandermeersch, 2014, Hoefnagels, 2010, Hertwich, 2005) and CE - Circular Economics (Ellen MacArthur Foundation, 2015b), which are now common practices in waste management and system assessment in the food industry (Mirabella, 2014). However, all current technologies and relevant management systems with respect to household kitchen waste treatment have drawbacks, especially when they are considered in the context of Circular Economics (CE) and Towards Zero Waste.

With respect to home composting, the CH_4 release per mass of material treated is less compared to commercial composting (Ermolaev, 2014, Andersen, 2010) and consequently has less environmental impact. However, it is difficult to fit into high-rise buildings and high-density residential neighbourhoods. Biological processing on a large scale presents issues with acidification, eutrophication and cadmium residues (Chiew, 2015), and there is also a need for pre-treatment in mechanical–biological treatment plants (Romero-Güiza, 2014) or for source separation procedures (Matsakas and Christakopoulos, 2015). For thermal and thermochemical technologies, there are problems of high water content, low energy efficiency and the complexity of FW (Hill, 2014, Pham, 2015). Before proceeding with the above technologies for the treatment of domestic food waste, a large-scale management support system involving collection, transportation and sorting is required. All these activities take considerable resources including land area, manpower, energy etc., resulting in significant environmental impacts - as Palmer (2004) has said: "The money that is wasted on garbage collection and dumping is money that is spent to destroy our planet". These considerations point towards the development and adoption of more localized and scaled down systems.

The concept of circular economics (CE), as it may be applied to the process of converting resources to consumable goods, is increasingly gaining acceptance as an alternative to the traditional line-directional approach where consumption and disposal are seen as the end point of resource utilization. The statement of "waste does not exist" is holistic and restorative and may be represented generically by the 'value circle' schematic (Ellen MacArthur Foundation and McKinsey & Company, 2014). CE may change "the structure of a system" (Meadows, 2004). However, this changing may be limited within an industrial economy (Ellen MacArthur Foundation and McKinsey & Company, 2014), especially with the characteristic of FW management system (Clift et al., 2000). Therefore, when applied to a specific problem (i.e. 'Micro' Circular Economics, MCE, as might be applied to households or small communities) - that potentially involves circular material flows - such as the management of HFW, the framework of CE has become 'less relevant'.

Within this context, different countries tend to develop different waste management systems depending on their specific political, economic, cultural and geographic circumstances (Lofgren, 2015). The adoption of a Micro-Circular Economic (MCE) approach with respect to household waste could encourage the adoption of a more standardized approach on a political level. This is illustrated by the dotted green line in Figure 5.1. Thus, the MCE concept focuses on the activities of individuals (i.e. households or small communities), who's collective influence will extend upwards to influence political decision-making and policy formation. Therefore, the MCE approach has the potential to affect "bottom-up" change.

From the systematic review of food waste treatment technologies carried out in Chapter 2, it may be seen that only ~ 26% (5 out of 19) of the available research involved economics and only ~ 10% (2 out of 19) of them consider social impacts. This finding is in agreement with the research reported by Zaman (2010) who find that most research on FWT/FWM (technology and management) does not consider socio-economic factors. A reason for this is that there is not enough available data relating to household FW treatment (Monier, 2010, Mason, 2011).

Therefore, there is an imperative for obtaining more information from individual households on their management and attitude towards household food waste. This will inform the development of more localized waste management and the development of appropriate supporting technologies. In this regard, it should also be acknowledged that all households are not equivalent. For example, the geographic location of a household or the dwelling type will influence the response. This problem has been specifically addressed in this thesis whereby a broad survey has been designed and conducted that probes the influence on domestic food waste management of geographical location and more importantly, dwelling type, within the Melbourne metropolitan area.

The survey strategy involved identifying three different types of geographical location and three different types of dwelling types that tend to be associated with geographical location, for surveying purposes. Thus, three councils were selected and enlisted for co-operation in this exercise. These have been described previously in Chapter 4.

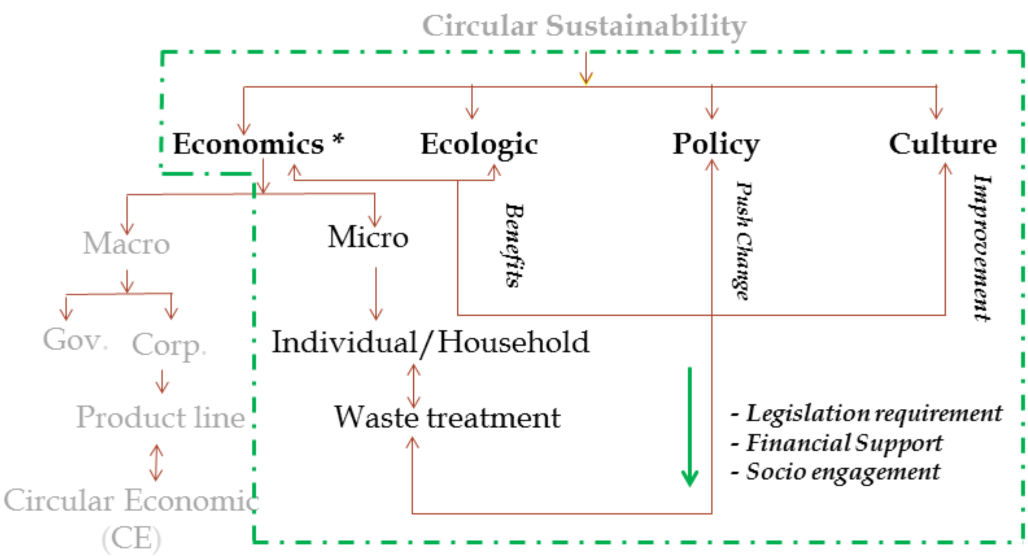


Figure 5.1 Circular-Economic and "Micro-Circular-Economic" Framework

5.2 Survey Methodology

5.2.1 Survey strategy

A household food waste (HFW) survey was designed and developed with the assistance of three council collaborators. The details of this survey are given in Section 5.2.3 below. The survey was intended to target house-hold occupants in three different geographical areas of Melbourne (the CBD, an inner suburb and an outer suburb). These three areas were represented by the City of Melbourne, the City of Yarra and Wyndham City, respectively - see Chapter 4. *Apart from their geographical differences, these three areas are also expected to have different preponderances of dwelling types.* For example, the City of Melbourne (CBD) has a higher representation of high-rise accommodation (high density), the City of Yarra - a higher representation of low-rise apartments (medium density) and Wyndham City - a higher representation of stand-alone detached houses (low density).

The results of the survey were expected to reflect differences in attitudes to domestic food waste management depending on *both* geographic location and also, specifically, dwelling type. Therefore, conducting the overall survey was found to require four "Runs" that are described in detail in Table 5.1. In order to maximize the number of responses in each category of geographical location and dwelling type, the responses from each "Run" were analyzed and combined into geographical and dwelling type categories as depicted in Figure 5.7.

Thus, conducting this survey presented a number of interesting challenges, summarized as follows. For capturing residents of Wyndham City (Run 1), it was possible to obtain a sizeable response from one of their local community events, i.e. the Victorian Rose Garden Show in November 2017, whereby the author and supervisors were able to utilize a Council stall to personally survey passers-by, Figure 5.2. Here, the response rate was very good, and it was possible to obtain 337 valid responses to the paper survey. In order to conduct the remaining surveys, it was deemed necessary to provide access to the survey via a website, utilizing Survey Monkey[11]. Therefore, a suitable website was created with

[11] The appropriate ethics approval was obtained from VU and the relevant documentation is provided in Appendix 5.1

an accompanying "flier" and a prize incentive. This flier is shown in Figure 5.3. By this method, responses could be obtained from various sources. Firstly, the website was made accessible via a City of Melbourne media website[12] (Run 2). This resulted in 307 responses, albeit from a variety of geographical regions and dwelling types. Secondly, the same flier was also "mail-dropped" by a "delivery boy" to a number of high-rise apartment blocks in the CBD, Figure 5.4[13] (Run 3). The delivery boy was nominated by the council - due to our not having access to the high-rise mailboxes. This resulted in 71 responses. Thirdly, the flier was delivered on-foot by the author and supervisors to a number of "low-rise" apartment blocks in the City of Yarra, Figure 5.5[14] (Run 4). Notably, this resulted in only 43 responses.

Table 5.1 Runs 1 to 4 of the overall survey

	Survey strategy	Time period	Respondent characteristics
Run 1	Paper survey via passers-by at community event of the Victorian Rose Garden Show, City of Wyndham	12th – 13th of November, 2017	Mainly detached dwellings in various locations
Run 2	Online survey via Melbourne City Council media website	1st of January – 27th of May, 2018	Various geographical locations and dwelling types
Run 3	Online survey via outsourced mail-dropped flier	28th of May – 31st of August, 2018	CBD / mainly high-rise dwellings
Run 4	Online survey via "on-foot" flier delivery	1st of September – 31st of October, 2018	City of Yarra / mainly low-rise dwellings

The above survey strategy and the specific nature of some of the survey questions allowed us to match the respondents to a particular dwelling type across all three of the geographical areas, Figure 5.7. This resulted in acceptable numbers of respondents in

[12] "Yammer" and "Greenmoney" newsletter.
[13] The detail of block information at CBD of Melbourne see Appendix 5.2.1
[14] The detail of block information at City of Yarra see Appendix 5.2.2

each category, Namely 342 for stand-alone detached houses (Figure 5.6), 232 for low-rise apartments and 183 for high-rise apartments.

Figure 5.2 The survey stall in Victorian Rose Garden Show in November 2018

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

To the Resident

You are invited to participate in a research program that is being conducted by VICTORIA UNIVERSITY, together with your local Council.

The aim of this research program is to find out the best way of dealing with Household Food Waste.

So we need information from individuals in the community about how people manage their domestic food waste. You can really help us in this research by completing a simple on-line survey!

The survey should take five to ten minutes to complete.

There is also an option for you to provide your email address within this survey if you want to receive ongoing information on the progress of this research.

Every email address entered will go into a draw for a prize of a “Fitbit Charge 2” - valued at $250!

Please note: You have to be over 18 to complete this survey and you have the option to remain completely anonymous.

To start the survey, please go to the webpage:
http://staff.vu.edu.au/hfw/

THANK-YOU for your time and contribution.

Figure 5.3 Survey invitation flier

Figure 5.4 The high-rise apartment blocks in the CBD

Figure 5.5 “low-rise” apartment blocks in the City of Yarra

Figure 5.6 Detached house in the City of Wyndham

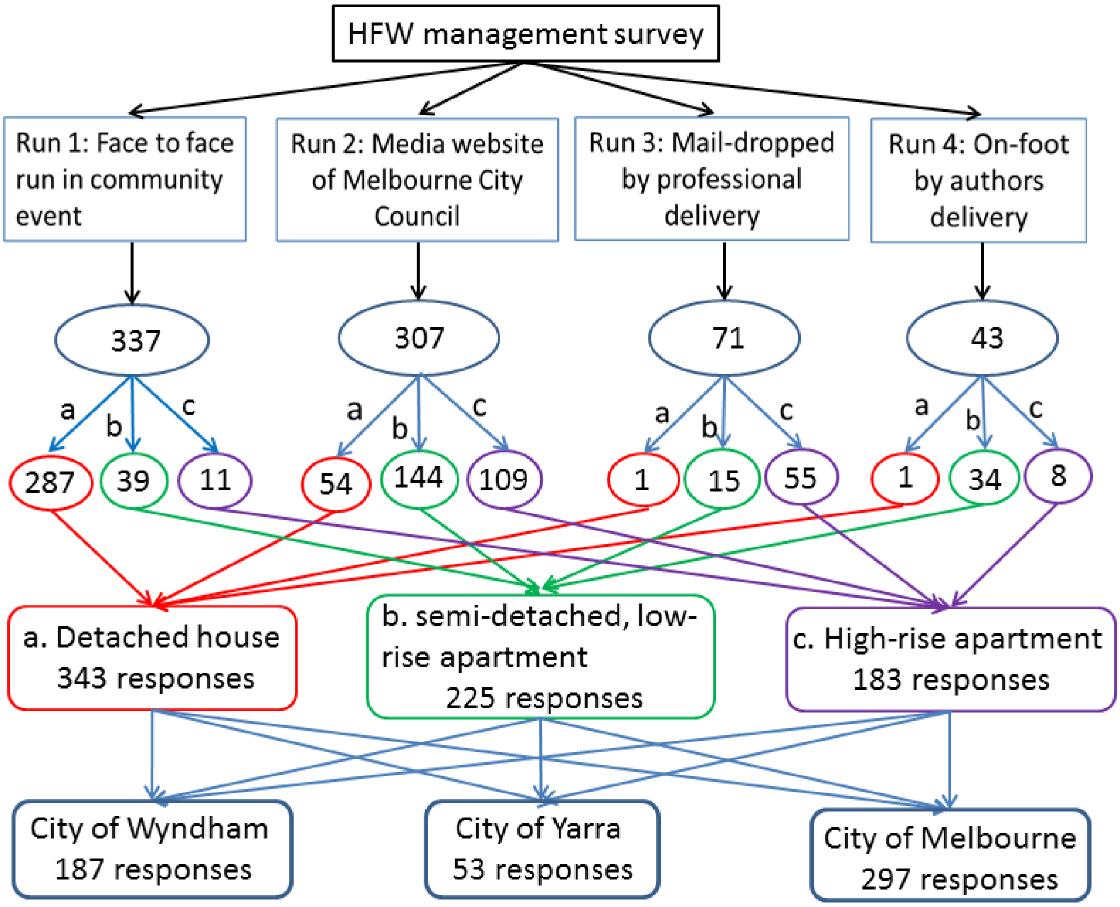


Figure 5.7 A schematic depicting the Household Food Waste (HFW) management survey strategy. The three geographical locations represented are: the City of Wyndham, the City of Yarra and the City of Melbourne; respondents were assigned to these locations based on their postcode that was requested in the survey. The three different dwelling types a, b and c, were assigned to respondents based on their responses to a number of questions in the survey. Details of Runs 1 to 4 are given in Table 5.1.

5.2.2 Sample size established

The sample sizes were established by using formula of the SurveyMonkey[15]. Here the confidence level refers to the percentage of all possible samples that can be expected to include the true population parameter. The Margin of error is the range of values below and above the sample statistic in a confidence interval. And the confidence interval is a way to show what the uncertainty is with a certain statistic[16]. According this formula, the sample size needed for each city councils was determined and listed in Table 5.2

[15] https://www.surveymonkey.com/mp/sample-size-calculator
[16] http://stattrek.com/statistics/dictionary.aspx?definition=confidence_level

below. One household is accounted as one unit. The Confidence Level of the survey will be set at 85%.

Table 5.2 Calculated sample size for each city

City	population	households	Sample size	Survey number	Respond rate	Confidence level	Margin of error
City of Melbourne (CBD)	133,388 (35,159)	63,100 (17,853)	207 (205)	2080 (2070) (online)	10 %	85 %	5%
City of Yarra	88,120	39,431	207	070 (online)	10 %	85 %	5%
City of Wyndham	209,750	71,137	207	360 (on-site)	58 %	85 %	5%

5.2.3 Survey questionnaire design

The survey itself is shown in Figure 5.8. The questions were designed to encompass the four elements of Micro Circular Economics (MCE), Figure5.1. Thus, Questions 1 and 2 indicated the geographical location and dwelling type of the respondent. Questions 3 and 4 requested basic family information and Questions 5, 6, 8 and 9 requested more personal information such as gender, age, education and occupation. Questions 7, 11, and 12 explored the eating habits of the respondent. Question 10 showed the current HFW disposal method used by the respondent. Questions 13 and 14 investigated the preferred method of HFW disposal. Question 15 and the remaining three questions investigated the attitude of the respondent towards HFW management in relation to regulation, environmental awareness and technology, with a provision to make suggestions.

Apart from the questions relating to demographics, it was deemed important to investigate eating habit, given that it has been shown that about 32% of food consumed is from outside the household (Sibrian et al., 2016). It has been estimated that the major components of HFW are meat, fruit & vegetables and bread & bakery products (Ren et al., 2018). Therefore Question 12 only was designed based on these categories.

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Household Food Waste (HFW) Survey

****

Victoria University and your local Council are interested in making the best use of Household Food Waste (HFW) and we need information from individuals in the local community about how you manage your food waste.

Note: ***You have to be over 18 to complete this survey. This survey is anonymous, and you will not be identified with the completed survey form.***

****

Please answer the following questions:

Q1 ***What is your postcode?***

Q2 ***What is the best description of your dwelling?***
□ detached house □ semi-detached house or town house □ apartment/high-rise

Q3 ***How many people are in your household?***
Adults: Children (under age 18):

Q4 ***What is the current status of your dwelling?***
□ owned outright □ rented □ mortgaged □ public housing

5 ***What is your gender?***
□ female □ male □ other

Q6 ***What is your age range?***
□ 18 – 24 □ 25 – 44 □ 45 – 59 □ 60 - 74 □ 75 +

Q7 ***Please estimate the number of days per week that you:***
Cook your own food: ____ /per week
Use fast food/takeaway: ____ /per week
Eat out: ____ /per week

Q8 ***What is your educational level?***
□ Year 12 or less □ TAFE □ Degree □ Post-graduate

Q9 ***Please describe your occupation:***
□ Trade □ Professional □ Business owner □ Unemployed □ Retired □ Student □ Home duties

Q10 ***How do you currently disposal your food waste?***
□ Council provided garbage bin □ Council provided Green bin □ Home composting □ Garbage chute

Q11 ***Please provide an estimate of the percentage of food waste in your garbage bin per day? Tick the appropriate box.*** □ <20, □ 20 – 50%, □ >50%

Q12 ***Please provide an estimate of the percentage of each of the following components of your food waste.***
Fruit and vegetable___%; bread/pasta/other carbohydrates ___%; meat/bone/seafood ___%

Q13 ***Are you willing to separate your food waste from your other waste?*** □ Yes □ No

Q14 ***Ideally, what treatment would you prefer for your food waste?***
□ Other (please specify) □ Composting bin in backyard □ Disposal to garbage bin/chute □ Treatment at your kitchen sink - combined with appropriate technology to process the waste

Q15 ***What is most likely to motivate you to segregate your food waste? Please rank the following from 1 to 6 (1 being the most likely).***
Council regulation____, Peer pressure____, Economic benefit ___, Availability of separating and disposal technology___, Environmental reasons ____, Cleanliness/hygiene ____.

Please answer the following questions using a scale of 1 to 5 (1 – 'not valued', 5 – 'highly valued').

No.	Question	Rating (1 to 5)
1.	Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')	
2.	Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')	
3.	To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')	

Please answer the following question using the text box provided (*optional*).

Do you have any suggestions on what your local council can do with domestic food waste that might benefit your family and community?

THANKYOU FOR COMPLETNG THIS QUESTIONNAIRE

Figure 5.8 Resident survey questionnaire sheets

5.3 Survey results and discussion

This survey strategy is depicted schematically in Figure 5.7. The results of the overall survey are to be discussed from two aspects, “dwelling type” - with reference to geographical location since the three different geographical locations each relate closely to the preponderance of a particular dwelling type. Thus, three different dwelling types have been specified, namely: detached house, semi-detached townhouse/low-rise apartment and high-rise apartment. By conducting a carefully constructed survey across three geographical locations and hence across the three different dwelling types it is possible to assess the range of attitudes to and management of HFW and to the potential introduction of new technologies. As expected, upon analysis of the survey data (see later), each of the three geographical regions has indeed a preponderance of a particular dwelling type. Thus, for central Melbourne, 76.1% of respondents were found to be in high-rise dwellings, for inner suburbs, 75.5% of respondents were found to be in semi-detached houses/low-rise apartments and, for outer suburbs, 93.6% of respondents were found to be in detached houses. Within the body of this thesis the survey results are discussed for the three different types of dwelling. The corresponding and related results with respect to geographical location are included in Appendices (for Chapter 5) 5.5 for reference.

5.3.1 Some notes on the construction and interpretation of the survey

A retrospective assessment of the survey indicated that there could be some ambiguity in Question 2 with respect to the distinction between a semi-detached house/town house and apartment/high-rise. Ideally, more detail should have been provided to the respondents with respect to the description of dwelling types in Question 2. Fortunately, it is possible to reconcile the responses to Question 2 with the responses to Question 10, where the respondent is required to indicate their food waste disposal method. Those who selected ‘garbage chute’ could unambiguously be assigned to a high rise (tower) dwelling type. Semi-detached/town house (or low-rise) use council provided garbage bins and can been assigned on this basis.

Also, as explained in Section 5.2.1, for the purposes of this study, a high rise is defined to be a building that is greater than seven stories. This, of course, is a purely arbitrary cut-off and it is possible that some “high-rise type” garbage chutes may exist in some of the semidetached/townhouse (“low-rise”) dwellings – although this would not be expected to be common. Indeed, the data from Table 5.7 shows that 8.4% of respondents in the semidetached/townhouse category (low rise) have actually selected the use of a garbage chute.

5.3.2 Dwelling type

From Figure 5.7, it can be seen that there are 343, 225 and 183 valid survey responses that fall into the dwelling types (a), (b) and (c), respectively. For each of these, the responses to the individual questions have been analysed *within each dwelling type* and a comparison of the responses to the individual questions *between the different dwelling types* has also been assessed.

5.3.2.1 Dwelling type (a) - Detached house

There was a total of 343 respondents who were considered to live in a detached house, Figure 5.7. 287 (83.7%) of these came from Run 1 and 56 (16.3 %) came from Runs 2 – 4, Table 5.1. Within this dwelling type, the following responses were received and are discussed. The number of responses for each question is shown along the vertical axis within relevant figures included in the following discussion.

Q1 What is your postcode?

There were 109 Victoria postcodes represented. 73 came from Run 1 and 36 came from Runs 2 - 4. The postcodes 3024, 3029 and 3030 are the most represented (175 out of 343 in total).

Q2 What is the best description of your dwelling?

There was no apparent ambiguity in response to this question (*vide supra*). These respondents overwhelmingly responded to Q10 by selecting either council provided bins or home composting, see Q10 below.

Q3 How many people are in your household?

156 (45.5%) responses were family with children under 18. And 187 (54.5%) were adult only households. The average size of the family was 3.3 persons.

Q4 What is the current status of your dwelling?

164 households owned their house, 139 households were mortgaged, and 41 households were rental. The percentage breakdown is shown in Figure 5.9.

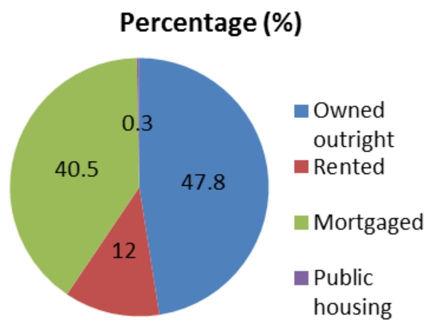


Figure 5.9 Detached house statuses

Q5 What is your gender?

207 of respondent were female and 135 were male. The percentage breakdown is shown in Figure 5.10.

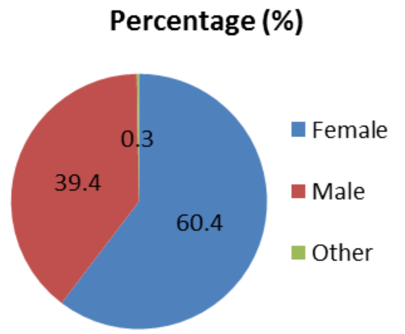


Figure 5.10 Gender of the responses in Detached houses

Q6 What is your age range?

Most respondents (137) were in the 25 - 44 year range (~ 40%), ~ 27 % (94) were in the 45 - 59 age range and ~ 27% in the 60- 74 age range. The younger (18 – 24) and older

(>75) age groups have lower representation (~ 2 and 3 % respectively) for this dwelling type, as might be expected. Figure 5.11 depicts the comparative percentage breakdown of the different age groups.

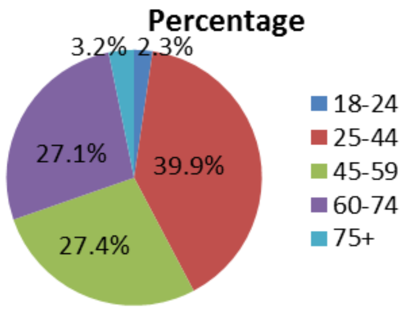


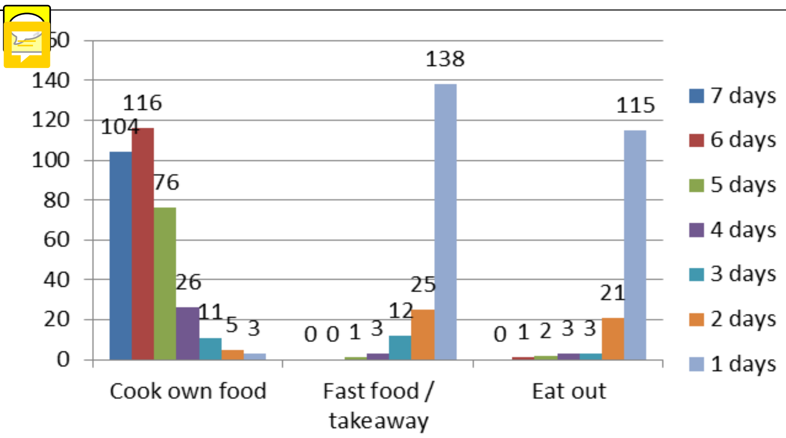
Figure 5.11 Detached house age distributions

Q7 Please estimate the number of days per week that you: Cook your own food: ____ /per week; Use fast food/takeaway: ____ /per week; Eat out:____ /per week.

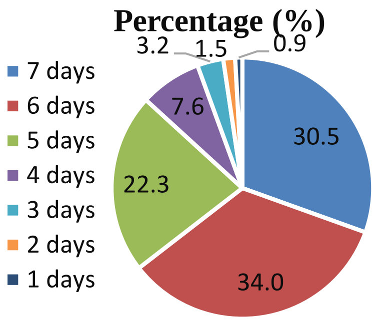
The responses to the question that outline eating patterns, have been summarized in Table 5.3 and Figure 5.12.

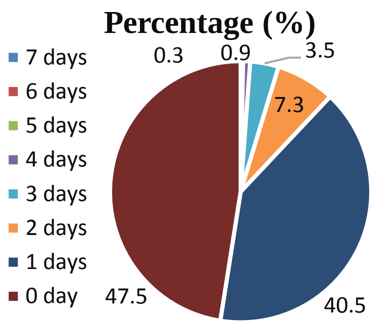
Table 5.3 Cooking/eating patterns for dwelling type (a) – detached house

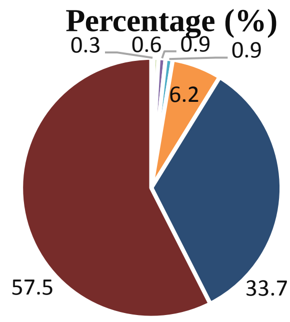
Number of days per week	Cook own food		Fast food / takeaway		Eat out	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
7 days	104	30.3	0	0.0	0	0.0
6 days	116	33.8	0	0.0	1	0.7
5 days	76	22.2	1	0.6	2	1.4
4 days	26	7.6	3	1.7	3	2.1
3 days	11	3.2	12	6.7	3	2.1
2 days	5	1.5	25	14.0	21	14.5
1 days	3	0.9	138	77.1	115	79.3
Total	341		179		145	



(a)







(b) **(c)** **d)**

Figure 5.12 Cooking/eating patterns in Detached house, (a) number of responses; (b) cook own food % breakdown; (c) fast food /takeaway % breakdown; (d) eat out % breakdown.

The above data demonstrate that for this dwelling type, over 86% of the families cooked their own food more than five days each week. Fast food/takeaway or eat out were only for one day or 0 day each week for most of the families. This data suggests that for this dwelling type the issue of food waste is likely to be significant.

Q8 What is your educational level?

Notably, ~ 60% of respondents hold a degree, Figure 5.13.

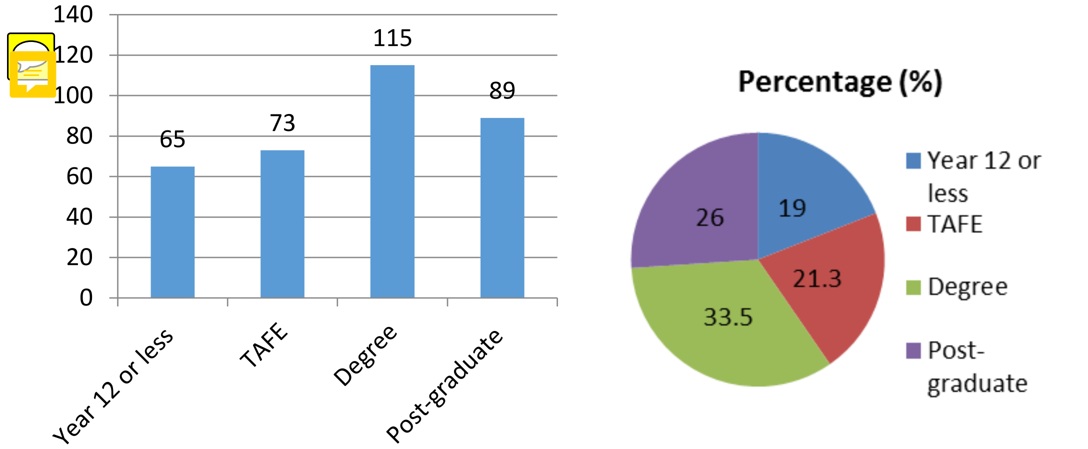


Figure 5.13 Educational levels of detached house occupants

Q9 Please describe your occupation:

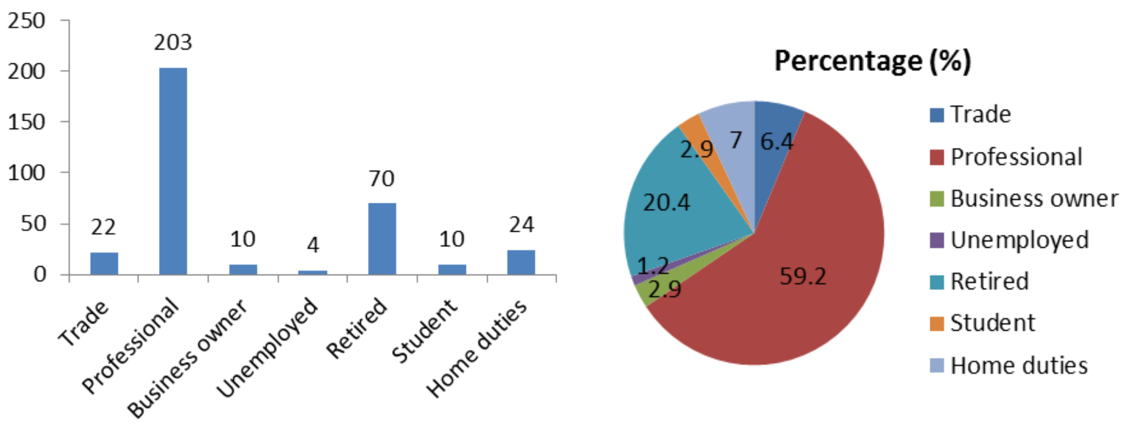


Figure 5.14 Occupations of detached house residents

Notably, ~ 60% of respondents were professional, Figure 5.14.

Q10 How do you currently dispose of your food waste?

☐ *Council provided garbage bin* ☐ *Council provided Green bin*

☐ *Home composting* ☐ *Garbage chute*

The responses to this question are summarized in Table 5.4.

Table 5.4 HFW disposal methods used by detached house occupants

	Garbage bin	Green bin	Home composting	Other
Number of total responses	197	54	115	78
Percentage	57.4%	15.7%	33.5%	22.7%

197 out of 343 respondents (57.4 %) used the council provided garbage bin and 169 (49.3%) used the green bin or home composting. Notably, 115 households (33.5 %) have their own home composting facility for their HFW.

Q11 Please provide an estimate of the percentage of food waste in your garbage bin per day? Tick the appropriate box. ☐ <20% ☐ 20 – 50% ☐ >50%

From the data presented in Figure 5.15, it is apparent that ~ 78% of respondents estimate that they have < 20% of food waste in their garbage bin on a daily basis, ~ 18% have between 20 and 50 % and ~ 4 % have > 50 %. These figures will have to be rationalized by comparison with the other dwelling types – see later.

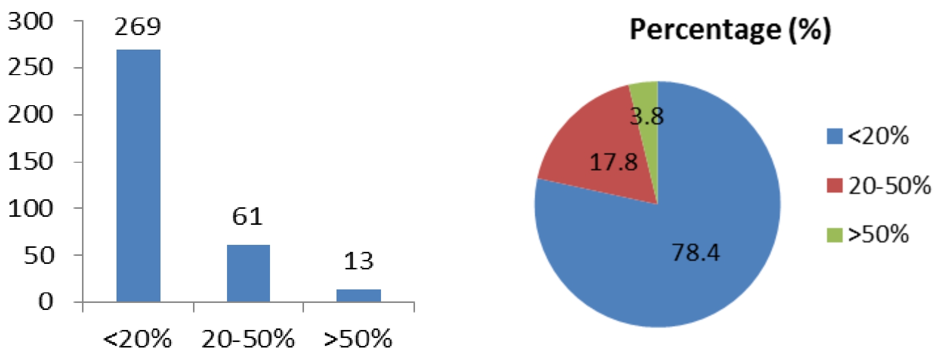


Figure 5.15 Percentage of food waste in garbage bin for detached dwellings

Q12 Please provide an estimate of the percentage of each of the following components of your food waste.

Fruit and vegetable___%; bread/pasta/other carbohydrates___%; meat/bone/seafood ___%.

The responses to this question have been summarized in Table 5.5 and Figure 5.16.

Table 5.5 Estimates of the three major components of HFW in detached dwellings

Range of the percentage breakdown	Fruit / vegetable		Carbohydrate		Meat / seafood	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
>69 %	134	45.1	6	2	14	4.7
30-69%	111	37.4	76	25.6	66	22.2
<30%	52	17.5	214	72.1	216	72.7
Total valid amount and average %	297	58	297	17.8	297	19.7

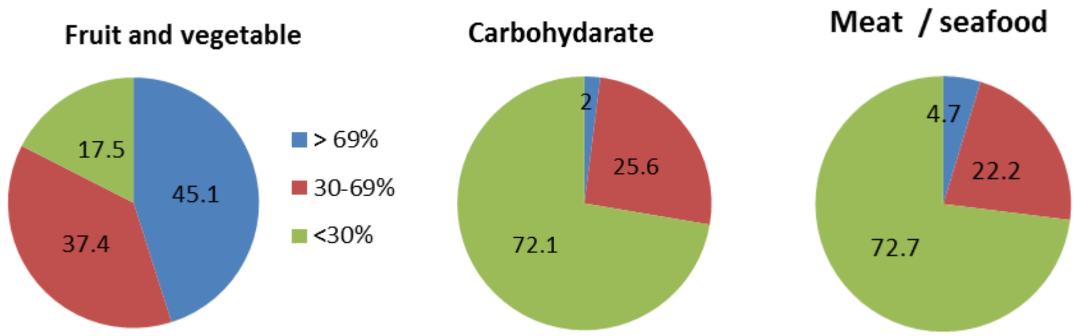


Figure 5.16 The percentage breakdown of the three major components of HFW in detached dwellings.

297 out of 343 data are considered valid, since the total percentage of the three components must add up to 100%. Most of the HFW were fruit/vegetable (58%) compared to carbohydrate and meat/seafood (17.8% and 19.7%, respectively). Also, most of the households have less than 30% of carbohydrate and meat /seafood waste in their HFW.

Q13 Are you willing to separate your food waste from your other waste?

An impressive 330 out of 343 (96.2%) of the households were willing to separate their HFW from other waste.

Q14 Ideally, what treatment would you prefer for your food waste?

☐ *Composting bin in backyard;*

☐ *Disposal to garbage bin/chute;*

☐ *Treatment at your kitchen sink - combined with appropriate technology to process the waste;*

☐ *Other (please specify)*

Responses to this question are shown in Figure 5.17.

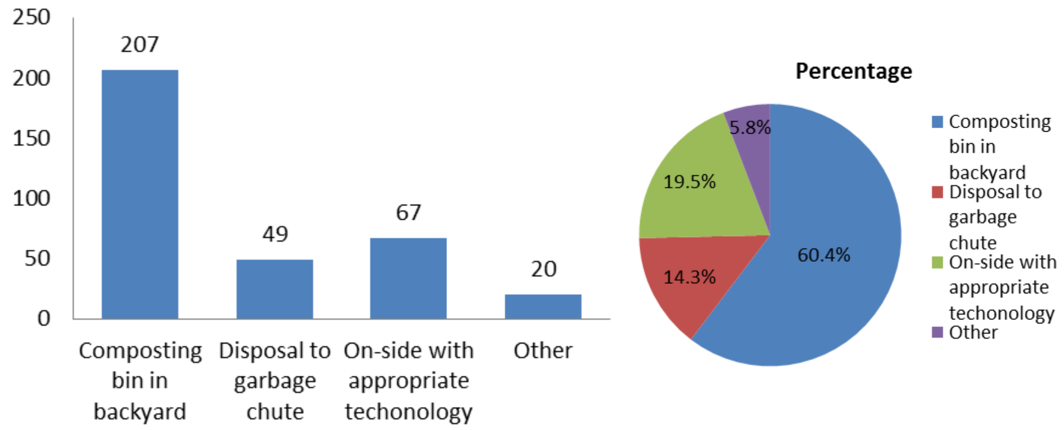


Figure 5.17 Preferred treatment method for HFW in detached dwellings.

A high proportion, 207 out of 343 (60.4%) of occupants preferred to have a composting bin in their backyard. 42 out of the 343 (14.3 %) selected a garbage bin and ~ 20% would consider "appropriate technology" on-site.

Q15 What is most likely to motivate you to segregate your food waste? Please rank the following from 1 to 6 (1 being the most likely).

Council regulation ____; Peer pressure ____; Economic benefit ____; Availability of separating and disposal technology ____; Environmental reasons____; Cleanliness/hygiene____.

The relative scores for the responses to this question are shown in Figure 5.18. In this question, a "6-point Likert scale" method is used for calculating the scores of each factor. Notably, environmental reasons are by far the most important motivation and peer pressure the least important. Economic benefit, available technology and cleanliness/hygiene were rated similarly, and council regulations were, perhaps surprisingly, rated second lowest.

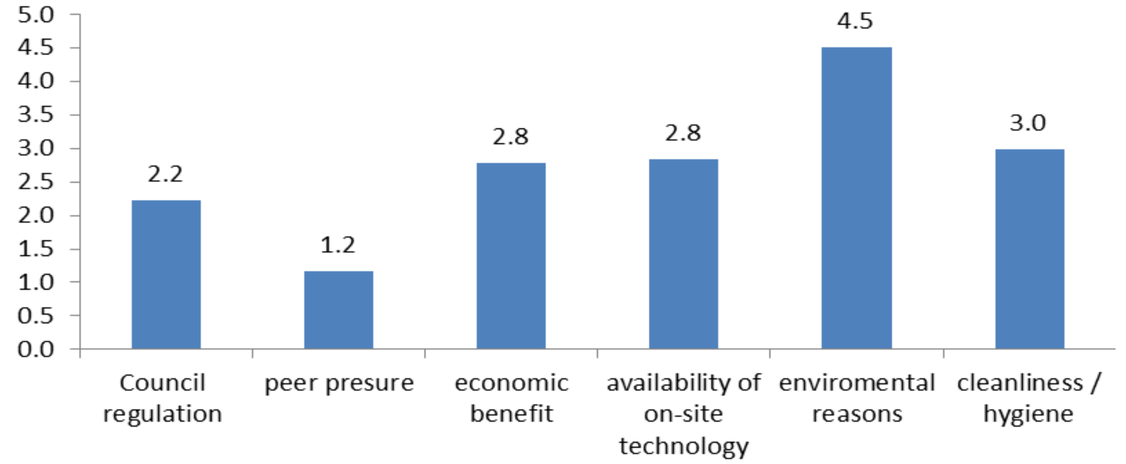


Figure 5.18 Motivation for segregation of HFW from other waste in detached dwellings. The vertical axis represents the calculated "score" - as described in Appendices 5.3 (Table 5.3.1)

Questions 16 to 18 require responses according to a 5-point Likert scale. These responses are shown in Figure 5.19.

The specific questions are as follows:

Q16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')

Q17 Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')

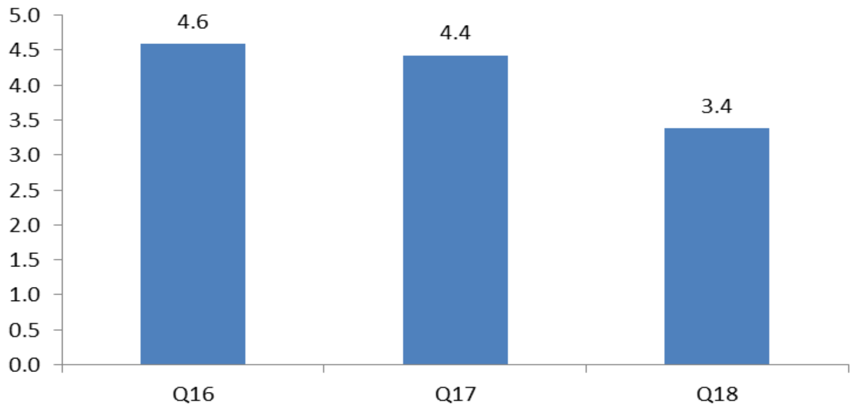


Figure 5.19 Average responses to Q16, Q17 and Q18 respectively left to right for detached dwellings. The vertical axis represents the calculated "score" – as described in Appendices 5.4 (Table 5.4.1)

The high response to Q16 shows that the day-to-day environmental impact of individuals is considered to be important to the respondent and associated subsequent generations. Similarly, a high score for Q17 shows a high acceptance for environmentally friendly practices and technologies. The response to Q18 demonstrates only a moderate awareness of environmental regulations relating to waste disposal.

5.3.2.2 Dwelling type (b) - semi-detached/town house (or low-rise)

There were total 225 respondents in this dwelling type, Figure 5.7. 40 (17.8%) of these came from Run 1 and 185 (82.2 %) came from Runs 2 - 4, Table 5.1. Within this dwelling type, the following responses were received and are discussed.

Q1 What is your postcode?

There were 49 Victoria postcodes represented.

Q2 What is the best description of your dwelling?

225 respondents were found to occupy semi-detached/town house (or low-rise) dwellings based on an analysis of Question 2 in conjunction with Question 10, Section 6.3.1.

Q3 How many people are in your household?

56 out 225 (24.9%) responses were families with one or more children under 18. The remainder were adults only. The average family size is 2.4 persons. This figure is similar to the average family size of Victoria and Australian (2.55) (.id - the population experts, 2019).

Q4 What is the current status of your dwelling?

Figure 5.20 shows the percentage breakdown of the ownership status.

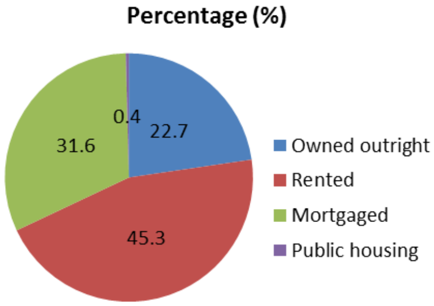


Figure 5.20 Semi-detached/town house (low-rise) statuses

Notably the proportion of rented dwellings is quite high at 45%.

Q5 What is your gender?

64% of participants were female (144). The number and percentage breakdown is shown in Figure 5.21.

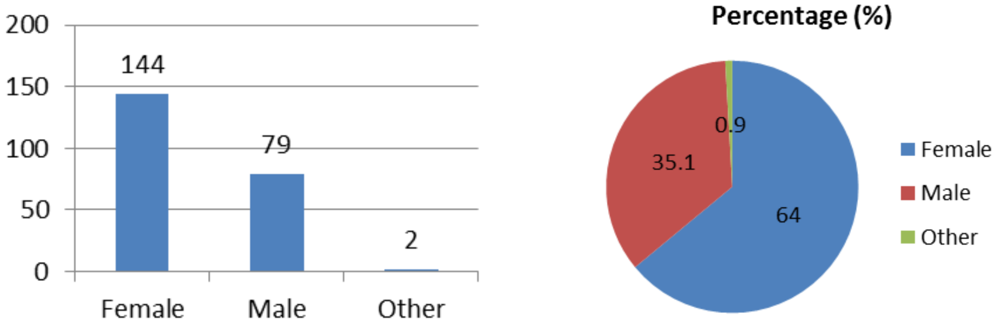


Figure 5.21 Gender of the responses in Semi-detached/town house (low-rise)

Q6 What is your age range?

Similar to the detached house survey, most respondents (150) were in the 25 - 44 year range (~ 65%). Also, the younger (18-24) and older (>75) age groups have a lower representation (~3 and 4 %, respectively) for semidetached and low-rise dwelling type - as expected. Figure 5.22 shows the distribution details and percentage breakdown of the different age groups.

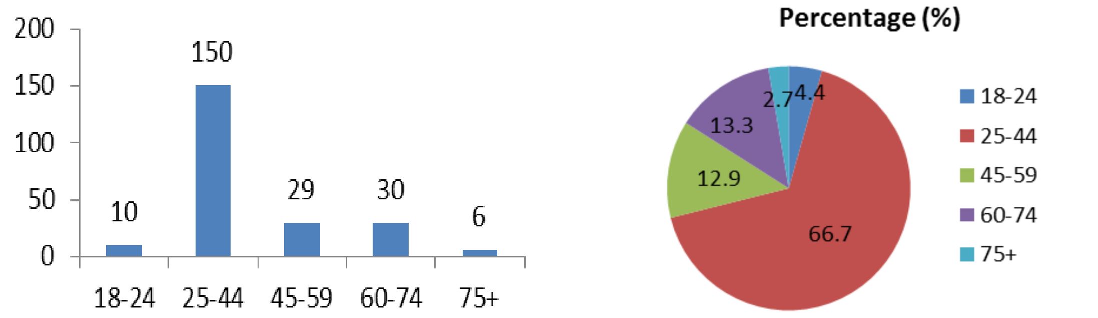


Figure 5.22 Semi-detached/town house (low-rise) age distributions

Q7 Please estimate the number of days per week that you: Cook your own food:___/per week ; Use fast food/takeaway:____/per week; Eat out:____/per week.

The responses to the question that outline eating patterns have been summarized in Table 5.6 and Figure 5.23

Table 5.6 Estimate cooking days of each week of the families who live in semi-detached/town house (low-rise)

Number of days per week	Cook own food		Fast food/ takeaway		Eat out	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
7	53	23.6	1	0.4	0	0
6	50	22.2	0	0	1	0.4
5	62	27.6	4	1.8	6	2.7
4	30	13.3	4	1.8	2	0.9
3	9	4.0	11	4.9	13	5.8
2	13	5.8	27	12.0	35	15.6
1	1	0.4	94	41.8	109	48.4
Total						

The above data demonstrate that for this dwelling type ~74% of the families cooked their own food more five days per week, and more than 42 -48% of them are fast food/takeaway or eat out at less once a week.

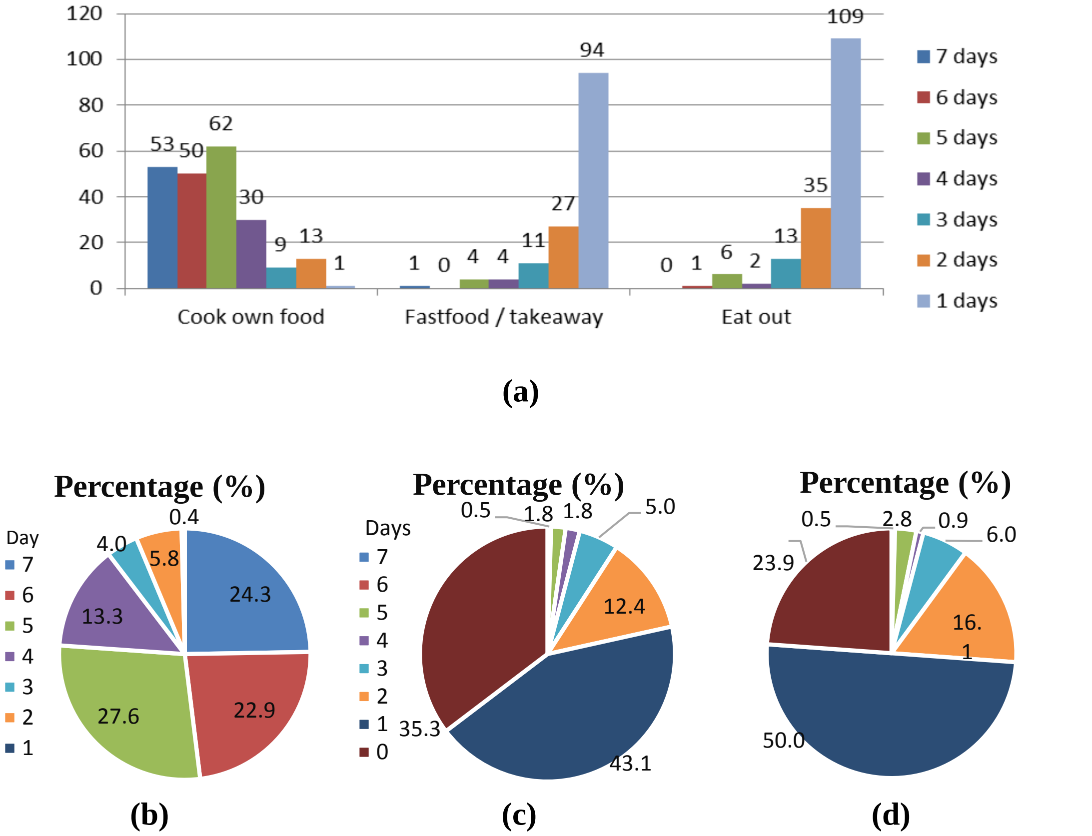


Figure 5.23 Cooking/eating patterns in semi-detached/town house (low-rise); a. number of the responses, b. cook own food, c. fast food / takeaway and d. eat out.

Q8 What is your educational level?

Figure 5.24 showed the detail of distribution of difference education level.

Over 82% of responses hold a degree. This demonstrates that in this type of dwelling, the overall education level is significantly higher than the average levels for Victoria (24.3%) and Australia (22%) (Statistics, 2016).

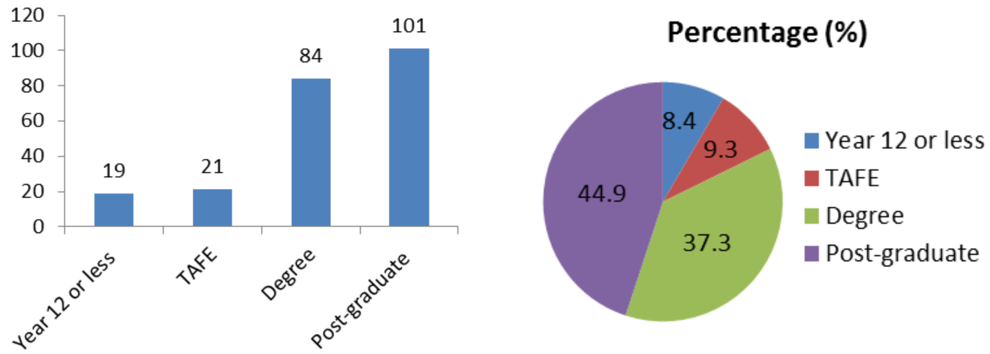


Figure 5.24 Education levels of semi-detached/town house (low-rise) occupants

Q9 Please describe your occupation:

A significant percentage, 71% of the respondents were professionals, Figure 5.25

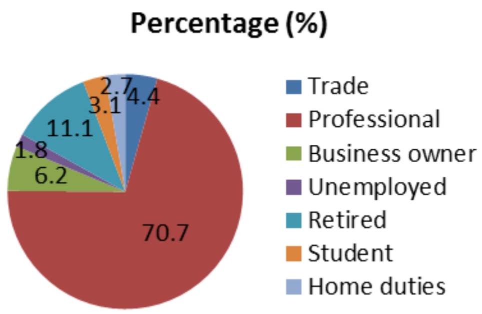


Figure 5.25 Occupations of semi-detached/town house (low-rise) resident

Q10 How do you currently disposal your food waste?

☐ *Council provided garbage bin* ☐ *Council provided Green bin*

☐ *Home composting* ☐ *Garbage chute*

The responses to this question are summarized in Table 6.7.

Table 5.7 HFW disposal methods used by semidetached/town house (low-rise) occupants

	Garbage bin	Green bin	Home composting	Garbage chute
Number of the response[17]	196	32	22	19
Percentage breakdown	87.1%	14.2%	9.8%	8.4%

It can be seen that the vast majority of these respondents use council provided bins and a minority use composting. These figures are as expected for this dwelling type. However, the small number who report the usage of a garbage chute is somewhat unexpected and could be related to the fact that a few of the higher apartment blocks of say five to seven stories could well have high-rise type garbage chutes - as outlined in Section 5.3.1.

[17] The reason these numbers add up to more than 100% is that some respondents have chosen more than one answer

Q11 Please provide an estimate of the percentage of food waste in your garbage bin per day?

☐ <20%; ☐ 20 – 50%; ☐ >50%

Figure 5.26 shows the data of the percentage of FW in the respondents' garbage bin on a daily basis. The data shows that ~ 70% of the families had less than 20% of HFW in their garbage bin per day; ~21% have between 20 to 50% and ~9% have >5%.

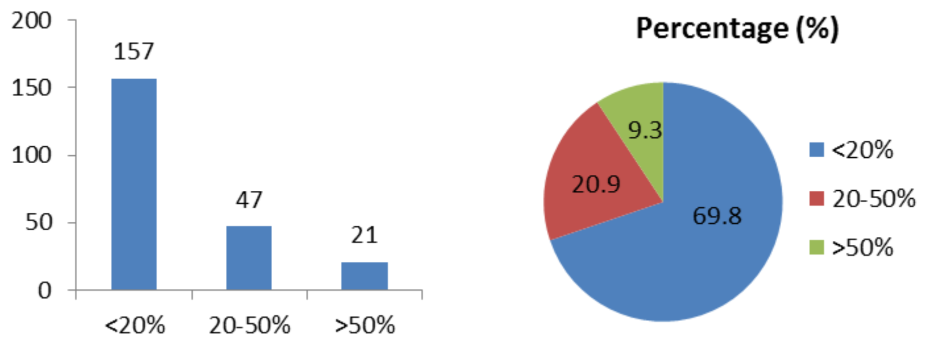


Figure 5.26 Percentage of food waste in garbage bin for semi-detached/town house (low-rise) dwellings

Q12 Please provide an estimate of the percentage of each of the following components of your food waste.

Fruit and vegetable___%; bread/pasta/other carbohydrates___%; meat/bone/seafood ___%.

The responses to this question have been summarized in Table 5.8 and Figure 5.27.

Table 5.8 Estimate of the three major components of HFW in semi-detached/town house and low-rise dwellings

Range of the percentage breakdown	Fruit and vegetable		Carbohydrate		Meat / seafood	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
> 69%	99	57.2	0	0	8	4.6
30-69%	57	33	39	22.5	42	24.3
<30%	17	9.8	134	77.5	123	71.1
Total valid amount and average %	173	64.5	173	15.4	173	20.1

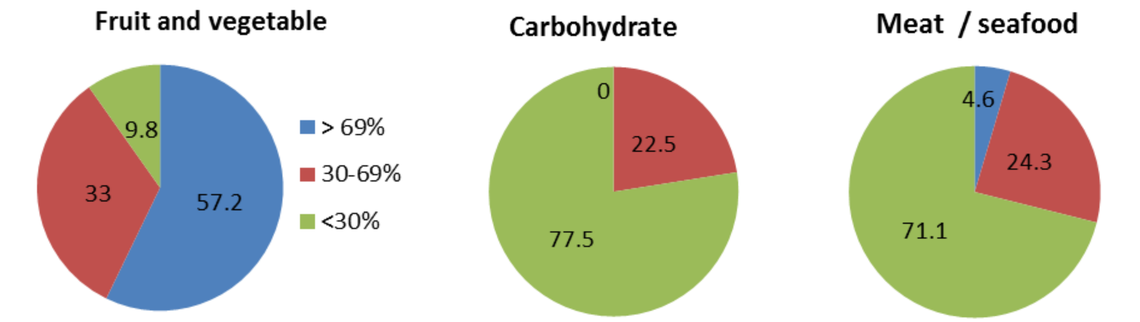


Figure 5.27 The percentage breakdown of three major components of HFW in semi-detached/town house (low-rise) dwellings.

173 out of the 225 data are considered valid. As expected, fruit/vegetable has the highest average percentage (64.5%) compared to carbohydrate and meat/seafood (15.4% and 20.1%, respectively), Table 5.17. Nearly three quarters of the household (77.5% and 71.1% are carbohydrate and meat/seafood, respectively) have less than 30% of these categories in their HFW, Figure 5.27.

Q13 Are you willing to separate your food waste from your other waste?

Impressively, 220 out of 225 (98%) of the households were willing to separate their HFW from other waste.

Q14 Ideally, what treatment would you prefer for your food waste?

☐ *Composting bin in backyard;*
☐ *Disposal to garbage bin/chute;*

☐ *Treatment at your kitchen sink - combined with appropriate technology to process the waste*

☐ *Other (please specify)*

Responses to this question are shown in Figure 5.28. Some household would use combining treatment methods for their HFW, therefore the total numbers of responses for this question are large than 225.

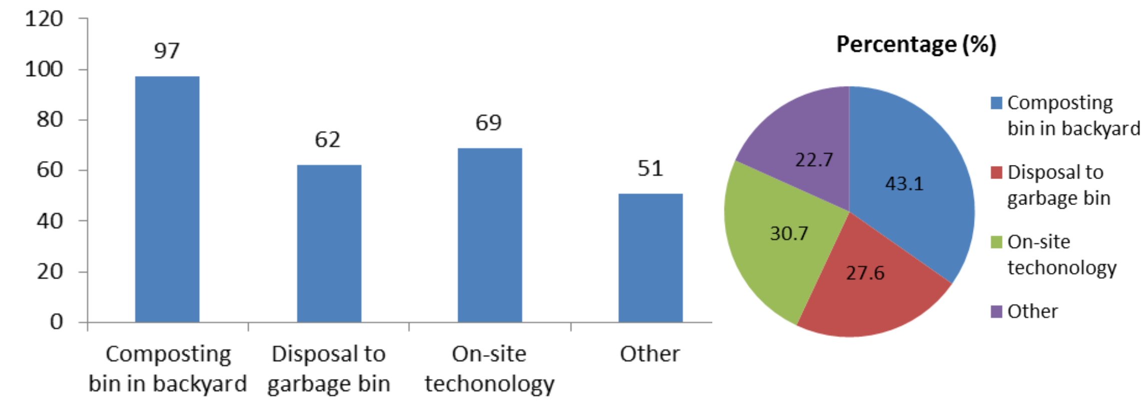


Figure 5.28 Preferred treatment method for HFW in semi-detached/town house (low-rise) households

Ideally, home composting (43.1%) following by on-site technology (30.7%) were the preferred HFW treatment for semi-detached/town house (low-rise) dwellings.

Q15: What is most likely to motivate you to segregate your food waste? Please rank the following from 1 to 6 (1 being the most likely).

Council regulation ____; Peer pressure____; Economic benefit____; Availability of separating and disposal technology____; Environmental reasons____; Cleanliness/hygiene____.

The relative average scores for the responses are shown in Figure 5.29. The availability of appropriate technology is rated the second most important motivation (4.2/6) after environmental awareness (4.6/6) and peer pressure the least important, which is same as that found with detached dwellings. Economic benefit and cleanliness/hygiene were rated similarly, and council regulation was rated the second lowest in HFW management.

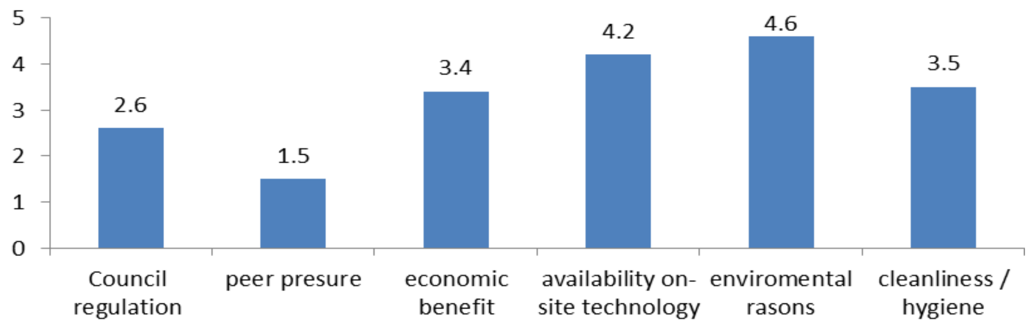


Figure 5.29 Motivation for segregation of HFW from other waste in semi-detached/town house (low-rise) dwellings. The vertical axis represents the calculated "score" - as described in Appendices 5.3 (Table 5.3.2)

As described previously, according to a Likert scale, the result of the responses to Q16 - Q18 are shown in Figure 5.30.

The questions are as follows:

Q16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')

Q17 Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')

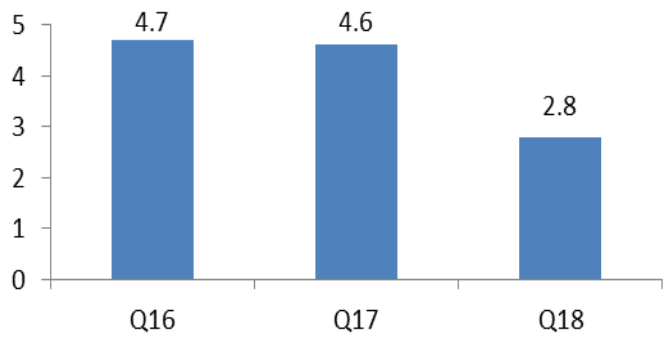


Figure 5.30 Average responses to Q16, Q17 and Q18 respectively left to right for semidetached /town house (low-rise) dwellings. The vertical axis represents the calculated "score" – as described in Appendices 5.4 (Table 5.4.2)

The high response to Q16 shows that the day-to-day environmental impact of individuals is considered to be important to the respondent and associated subsequent generations. Similarly, a comparable high score for Q17 shows a high acceptance for environmentally friendly practices and technologies. The moderate score is for Q18 regarding awareness of environmental regulations relating to waste disposal.

5.3.2.3 Dwelling type (c) - High-rise

183 valid responses were obtained from high-rise dwellers, as shown in Figure 5.7. Of the 183; 11, 109, 55 and 8 were from Runs 1 – 4 respectively.

Q1 What is your postcode?

There were 14 Victorian postcodes represented. 161 respondents came from 9 postcode suburbs of Melbourne City, and the remaining 22 respondents came from 5 postcodes in the Melbourne metropolitan area.

Q2 What is the best description of your dwelling?

The selected criterion of high-rise was apartment/high-rise with garbage chute.

Q3 How many people are in your household?

With the high-rise dwellings most residents were adult. Only 20 out of 183 (10.93%) families had children under 18. The average size of household is 2.1 persons.

Q4 What is the current status of your dwelling?

The numbers of dwelling status responses were 51, 80 and 52 for owned outright, rented and mortgaged, respectively. Figure 5.31 gives the percentage breakdown of each category.

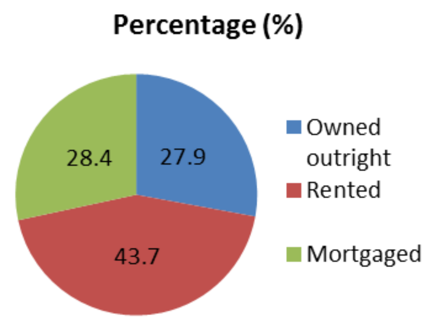


Figure 5.31 High-rise apartment statuses

Q5 What is your gender?

The percentage of female and male of responses in high-rise were 55.74% 43.17%, Figure 5.32.

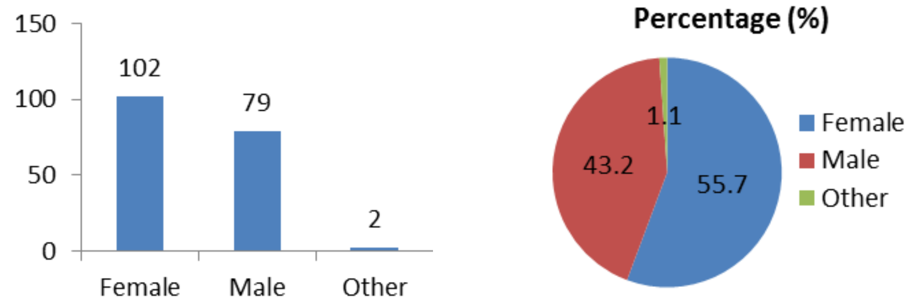


Figure 5.32 Gender of the responses in High-rise

Q6 What is your age range?

Up to 77.18% of responses living in high-rises were aged between 25-59 years old. The younger (18-24) and the 45-59 age ranges have close percentages (11.5 and 13.7% respectively). The 75+ age group and 60-74 age groups have a lower representation (~1.1 and 9.8% respectively). Figure 5.33 showed the comparative percentage breakdown of each age groups.

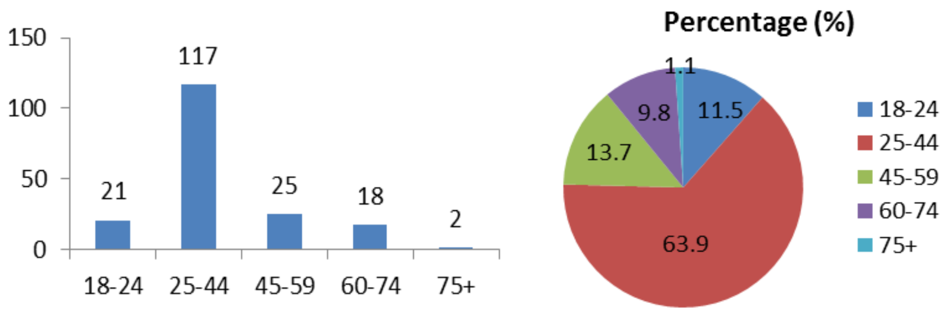


Figure 5.33 High-rise apartment age distributions

Q7 Please estimate the number of days per week that you:

Cook your own food____ /per week;

Use fast food/takeaway ____ /per week; Eat out____ /per week.

Table 5.9 and Figure 5.34 summarize the responses to the question that assess eating patterns.

Table 5.9 Number of days cooking per week - total and rate

Number of days per week	**Cook own food**		**Fast food / takeaway**		**Eat out**	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
7 days	23	12.6	0	0	1	0.6
6 days	35	19.1	0	0	0	0
5 days	60	32.8	10	5.5	7	3.8
4 days	21	11.5	6	3.3	4	2.2
3 days	19	10.4	13	7.1	13	7.1
2 days	12	6.6	22	12.0	43	23.5
1 days	4	2.2	67	36.6	90	49.2

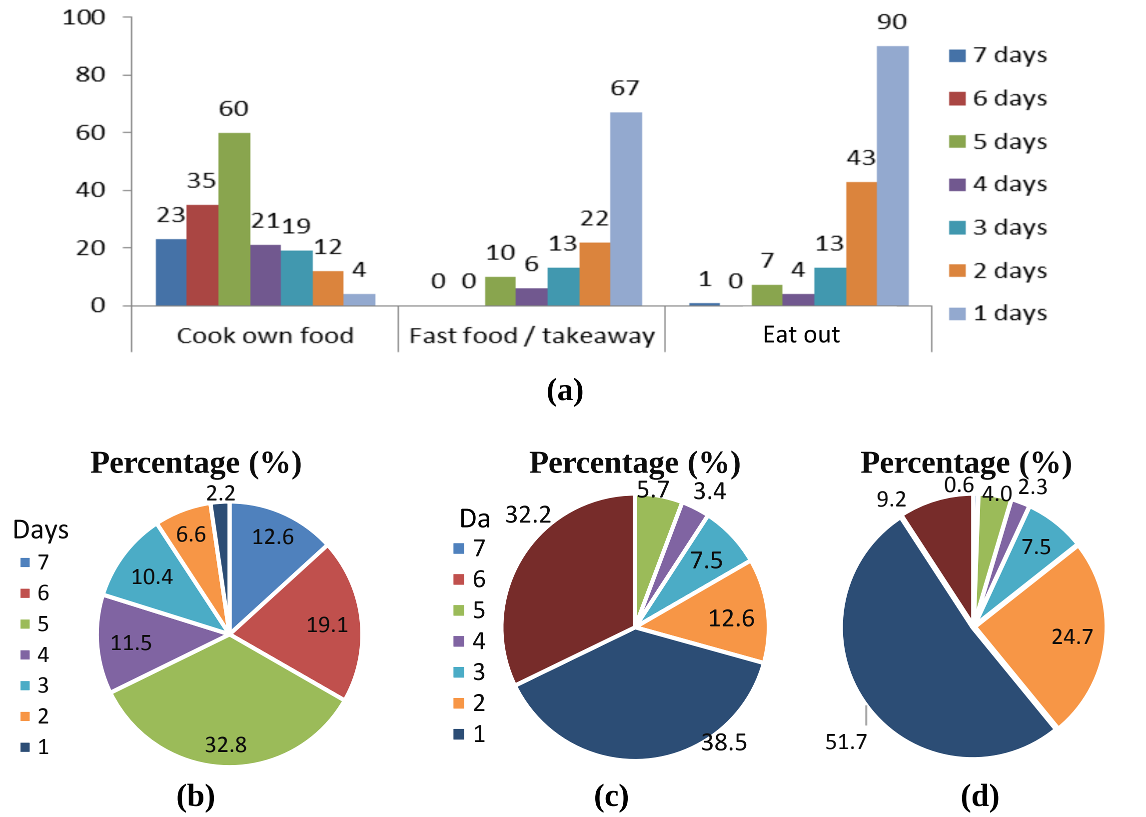


Figure 5.34 Cooking/eating patterns in high-rise, (a) number of responses; (b) cook own food % breakdown; (c) fast food/takeaway % breakdown; (d) eat out % breakdown

The above data demonstrate that ~ 65% of households cook their own food at home for five days a week or more, up to one week. Most of the families would have one to two days of fast food/takeaway (36.6 and 12%) eat out (49.2 and 36.6%) or fast food/takeaway (36.6 and 12%).

Q8 What is your educational level?

There is a significant percentage (90%) of respondents holding a degree. Figure 5.35 shows the detail.

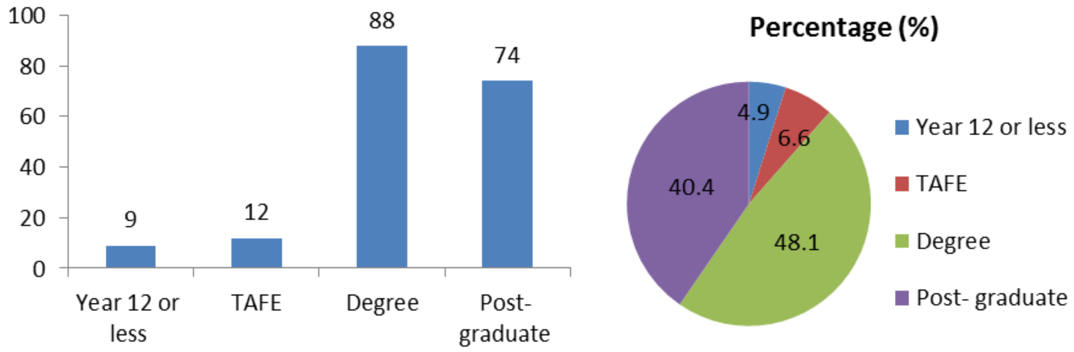


Figure 5.35 Education levels of high-rise apartment occupants

Q9 Please describes your occupation.

~70% of responses were professional, Figure 5.36.

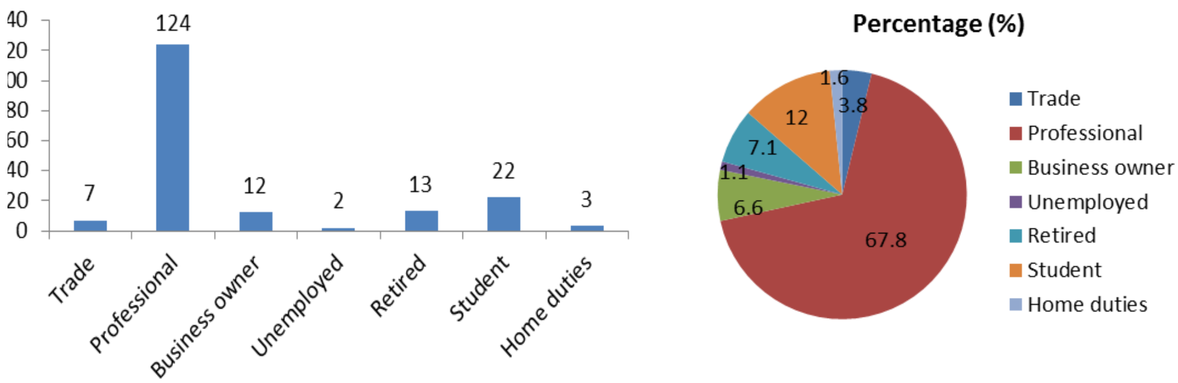


Figure 5.36 Occupation of high-rise residents

Q10 How do you currently disposal your food waste?

□ *Council provided garbage bin* □ *Council provided Green bin*

□ *Home composting* □ *Garbage chute*

All the high-rise dwellings used garbage chutes for their HFW disposal. This would be expected to facilitate the implementation of on-site building-based technology for HFW treatment.

Q11 Please provides an estimate of the percentage of food waste in your garbage bin per day? □ <20% □ 20 – 50% □ >50%

The estimated percentages of HFW in the garbage bins of the respondents are depicted in the graphs below. Notable, 74.3 % of respondents deposit less than 20% of their FW into a garbage bin and this reflects the fact that most residents would be depositing food waste directly into a chute.

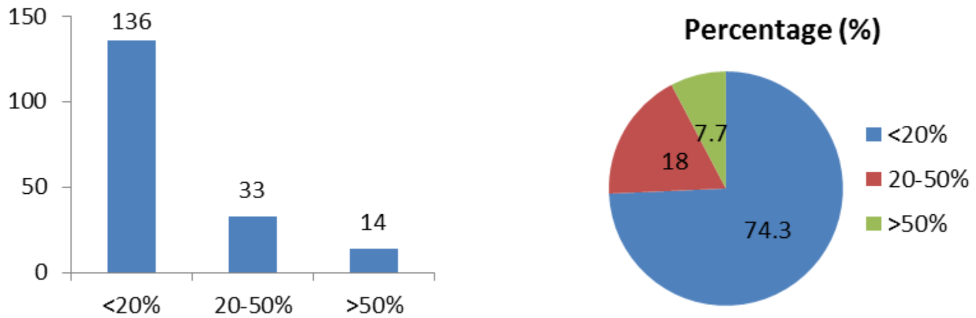


Figure 5.37 Percentage of food waste in garbage bin in high-rise dwellings

Q12 Please provide an estimate of the percentage of each of the following components of your food waste.

Fruit and vegetable___%; bread/pasta/other carbohydrates___%; meat/bone/seafood ___%.

The responses to this question have been summarized in Table 5.10 and Figure 5.38.

Table 5.10 The estimate percentage of HFW in three components

Range of the % breakdown	Fruit / vegetable		Carbohydrate type		Meat / seafood	
	Number of responses	Percentage (%)	Number of responses	Percentage (%)	Number of responses	Percentage (%)
>69%	52	40.6	6	4.7	4	3.1
30-69 %	55	43.0	36	28.1	43	33.6
<30 %	21	16.4	86	67.2	81	63.3
Total responses and average %	128	55.5	128	21.1	128	23.3

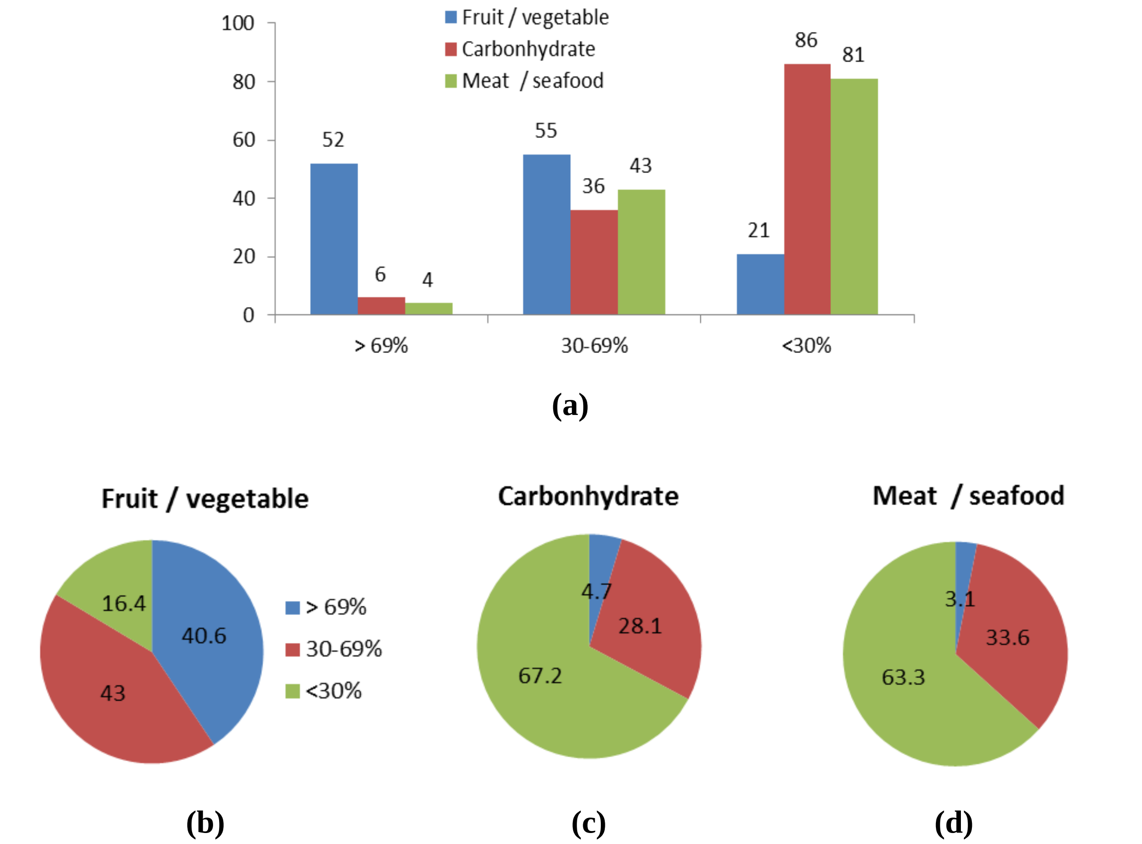


Figure 5.38 The percentage breakdown of three major components of HFW in high-rise dwellings

128 out of 183 are considered valid responses. The data indicates that the total percentage of fruit/vegetable waste is over double that of carbohydrate type and meat/seafood waste. Also, approximately 74% of the households had less than 30% of starch type and meat/seafood type waste.

Q13 Are you willing to separate your food waste from your other waste?

Again, it was pleasing to note that over 90 % of households (166 out of 183) were willing to separate their FW from other household waste.

Q14 Ideally, what treatment would you prefer for your food waste?

□ Composting *bin in backyard*

□ Disposal *to garbage bin/chute*

□ *Treatment at your kitchen sink - combined with appropriate technology to process the waste*

□ *Other (please specify)*

Responses to this question are shown in Figure 5.39.

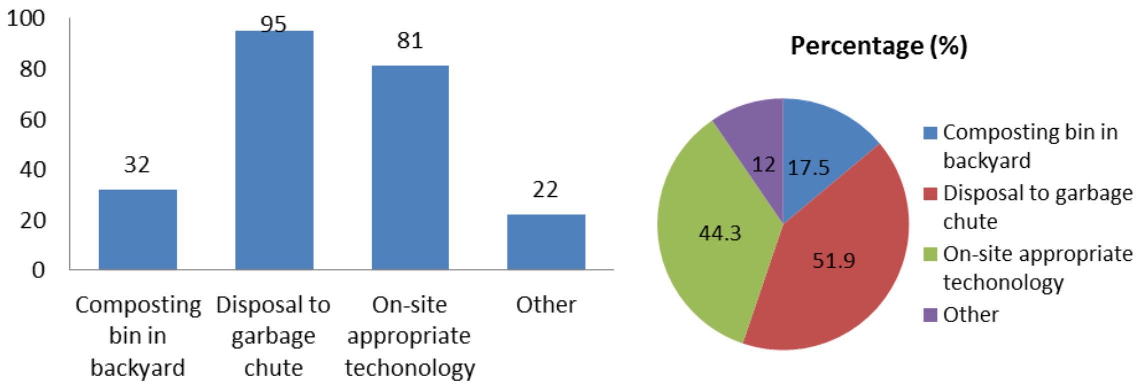


Figure 5.39 Preferred treatment method for HFW in high-rise dwellings.

Compared to other dwelling types, a much higher proportion, i.e. 81 out of 183 (44.3%), of occupants choose on-site appropriate technology second to garbage chute which is 95 out of 183 (51.9%). 22 out of 183 (12%) selected “other” that might include community composting bins for a community garden or a “Food-Bank” for food reuse.

Q15 What is most likely to motivate you to segregate your food waste (rank from 1 to 6 and 1 being the most likely)? Council regulation ____; Peer pressure____; Economic benefit ____; Availability of separating and disposal technology____; Environmental reasons ____; Cleanliness/hygiene ____.

The relative scores for the responses to this question are shown in Figure 5.40. The availability technology has the highest score (4.5 out of 6) following by the environmental reason (4.36 out of 6). These figures state that these two factors are by far the most important motivation rather than cleanliness/hygiene, economic benefit or council regulations. Peer pressure is the least important as with the other two dwelling types.

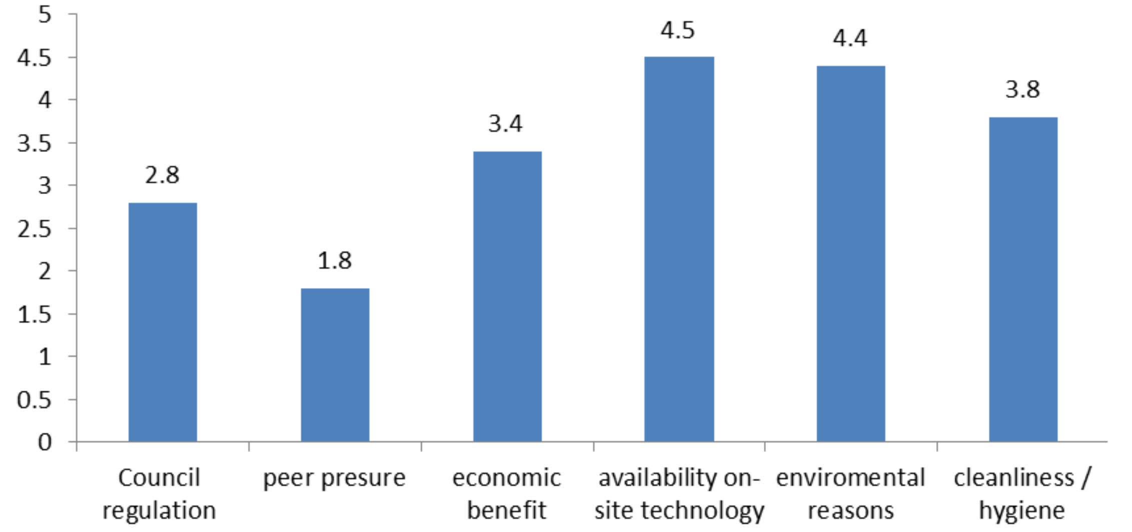


Figure 5.40 Motivation for segregation of HFW from other waste in high-rise dwellings. The vertical axis represents the calculated "score" - as described in Appendices 5.3 (Table 5.3.3)

The responses of Questions 16 to 18 are shown in Figure 5.41.

Q16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations (1 – 'not important', 5 – 'highly important')?

Q17 Do you and/or your family support the availability of environmentally friendly practices and technologies (1 - 'do not support', 5 – 'highly support')?

Q18 To what extent are you aware of environmental regulations relating to waste disposal (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')?

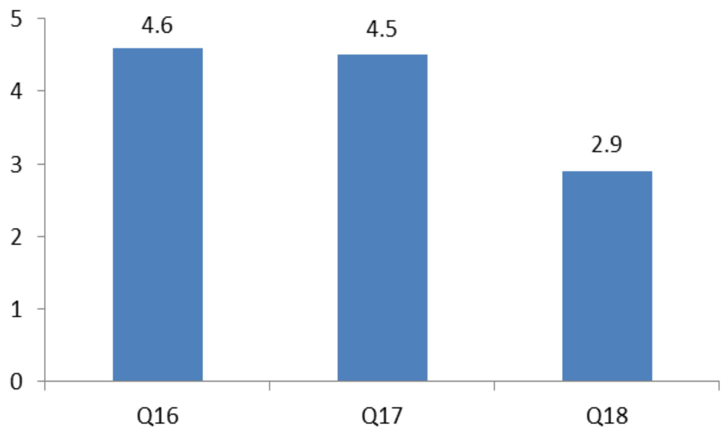


Figure 5.41 Average responses to Q16, Q17 and Q18 respectively left to right for high-rise. The vertical axis represents the calculated "score" – as described in Appendices 5.4 (Table 5.4.3)

The day-to-day environmental impact of individuals, Q16, is considered to be the most important (4.58 out of 5) and associated subsequent generations. Acceptance of environmentally friendly practices and technologies, Q17, has the second-high score - that is very close to Q16. Again, the response to Q18 demonstrates only a moderate awareness of environmental regulations relating to waste disposal.

5.3.3 Comparison between the three dwellings types

This section utilizes the preceding data to assess the differences in attitudes to HFW management *between* the three different dwelling types.

Q1 What is your postcode?

There are 109, 49 and 14 postcodes, respectively, that correspond to detached, semi-detached/town house (low-rise) and high-rise dwelling types. This is an interesting pattern, and it is, perhaps, not surprising that the number of post codes decreases upon moving to higher rise dwellings. This is reflective of housing patterns in Victoria and, probably, in Australia generally. This aspect of the survey could possibly be used in future studies to track changing housing patterns within a society.

Q2 What is the best description of your dwelling?

The detached houses have the highest proportion of 45.7% (343 out of 751) following by the semi-detached/town house (low-rise), 30% (225 out of 751). The high-rise apartment has the lowest proportion of 24.3% (183 out of 751). These are considered to be satisfactory distributions across the three dwelling types - given that the ease of surveying is dwelling type dependent. It was this issue that necessitated the development of a sophisticated survey strategy, Figure 5.7.

Q3 How many people are in your household?

The average family sizes are 3.3, 2.4 and 2.1 for detached house, semidetached/town house (low-rise) and high-rise apartment, respectively, Figure 5.42. This pattern is not surprising since one would expect a decreasing household size with an increase in dwelling “rise”. The average size of all three dwelling types combined is 2.6 and is identical to the average family size of Victoria and Australia families (2.6) (.id - the population experts, 2019).

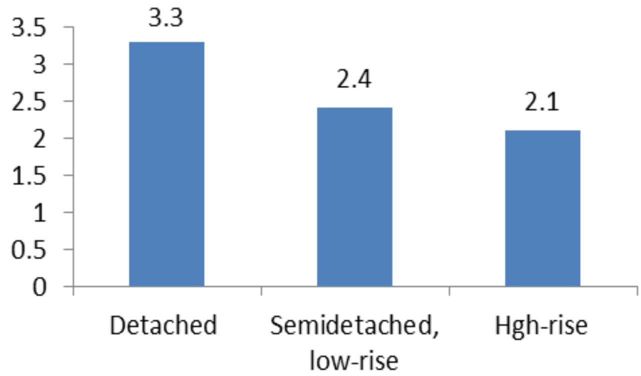


Figure 5.42 The family size within each dwelling type.

Q4 What is the current status of your dwelling?

Noticeably, detached dwellings are predominantly owned outright or mortgaged whereas the low- and high-rise dwellings are predominantly rented and more modestly mortgaged, Figure 5.43. Home ownership could well affect people's attitudes to HFW management, and this will also be considered later.

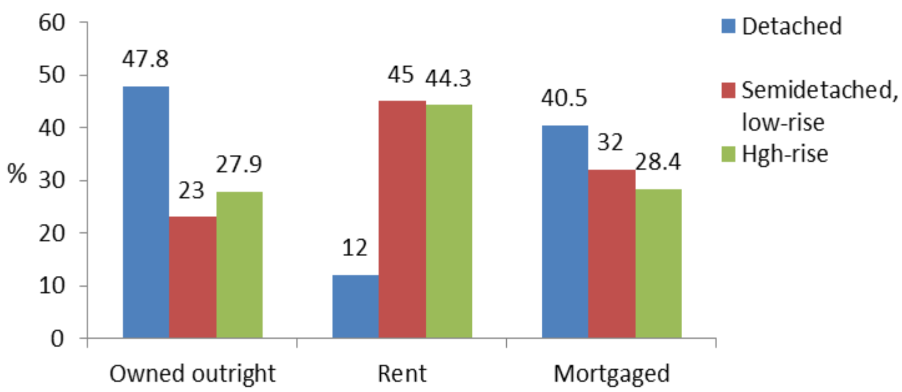


Figure 5.43 The status of each dwelling type.

Q5 What is your gender?

The percentage of female responses is higher than the males in all three dwelling type, Figure 5.44. This could reflect the traditional gender household roles whereby females are still disproportionally involved in household tasks such as cooking and cleaning. This might be a consideration when DFWM programs are presented to a target community, although targeting women this could be controversial with those who are also interested in addressing perceived gender inequalities.

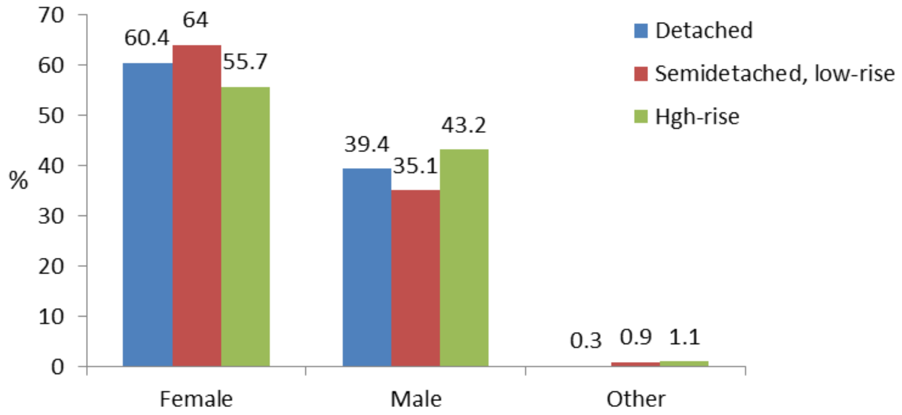


Figure 5.44 The gender of the responses across the three dwelling types.

Q6 What is your age range?

The highest response is from the 25 - 44 age group, Figure 5.45, with a preponderance of these in low- and high-rise dwellings. Detached dwellings have a noticeably broader distribution of age groups, ranging from 25 - 74. It is apparent that the younger people have a preference for the low- and high-rise dwellings.

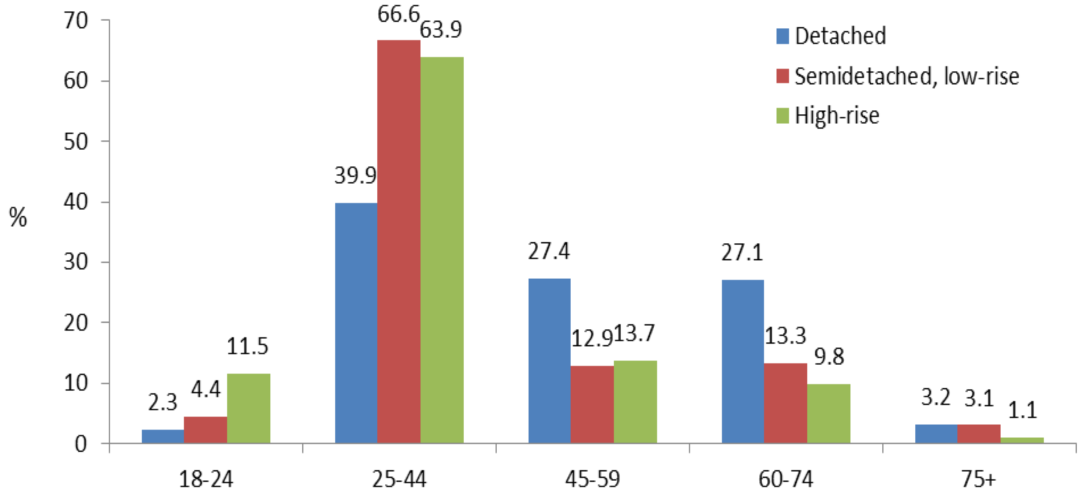


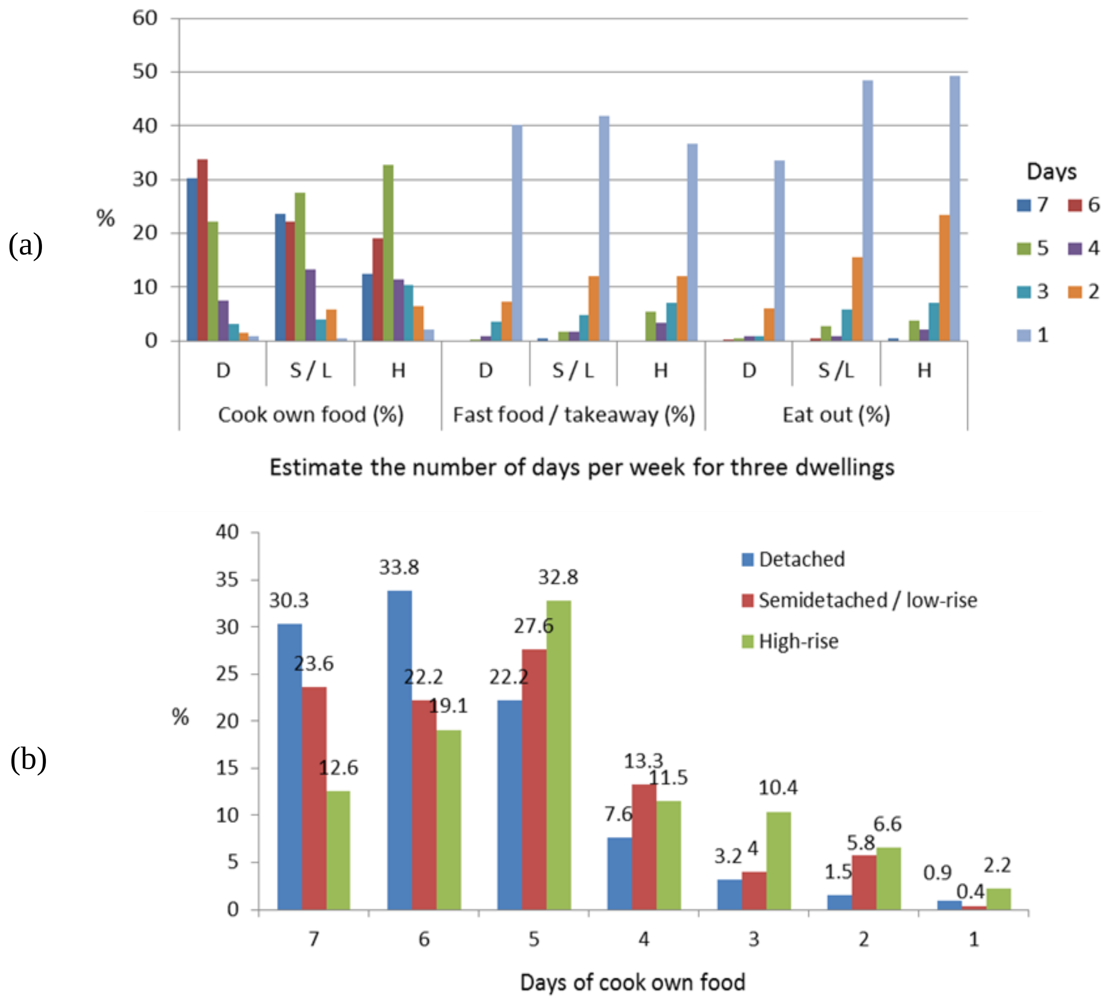
Figure 5.45 Age ranges across the three dwelling types.

Q7 Please estimate the number of days per week that you: Cook your own food____ /per week; Use fast food/takeaway ____ /per week; Eat out____ /per week.

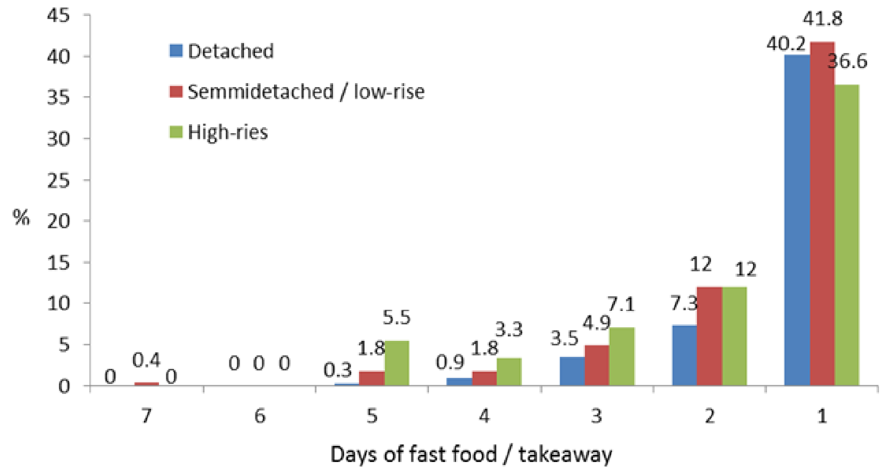
Figure 5.46 shows that eating patterns are dependent on dwelling type.

The overall response to this question, that probes the eating patterns of the occupants from the three different dwelling types, is shown in Figure 5.46 (a) (data details are provided in the Appendix 5.3.7 (Sheet 2)). From this graph, it is immediately noticeable that home cooking is the major eating activity across all dwelling types. It is also apparent that fast food/takeaway or eating out is mainly limited to 1-2 days per week across all dwelling types.

Figure 5.46 (b) shows how many days per week each dwelling type has home cooked food. It may be seen that, for all three types of dwelling, most occupants cook their own food for 5-7 days a week - being 86.3%, 73.4% and 64.5%, respectively, for detached, low rise and high rise. Notably, although the highest rate for detached dwellings is not surprising, the high rates for the low- and high-rise dwellings are significant in terms of FWM.



(c)



(d)

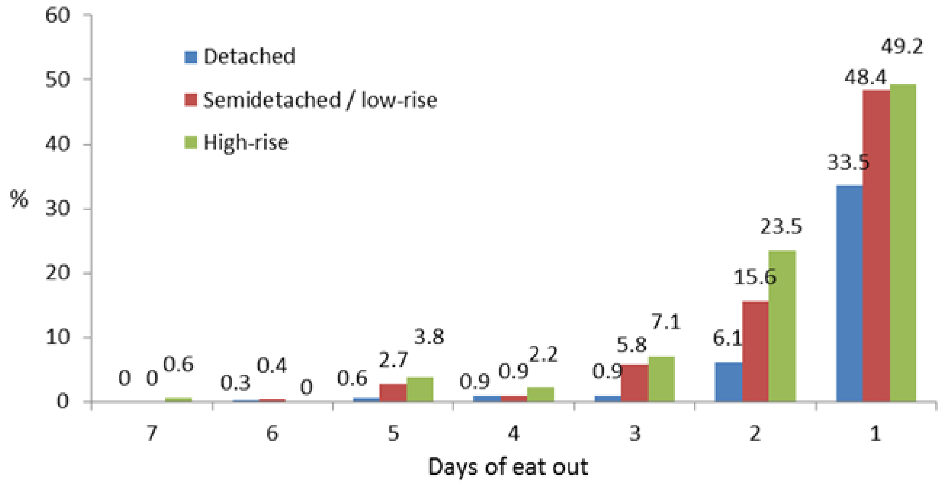


Figure 5.46 Eating patterns across the three dwelling types.

Figure 5.46 (c) and (d) highlights the fact that fast food/takeaway or eating out is mainly limited to 1-2 days per week across all dwelling types. This is, perhaps, contrary to what might be presumed about the lifestyles of those who live in low- and high-rise dwellings.

Prior to conducting this survey, it might have been expected that low- and high-rise occupants would have a high rate of fast food/take away or eating out compared to detached dwelling residents. Interesting, and importantly for FWM, this is observed not to be the case as such occupants actually have a high rate of home cooking.

Q8 What is your educational level?

The occupants of detached dwellings have a broad distribution of educational levels. However, the occupants of high-rise dwellings hold more higher degrees (88.5%) than the respondents from detached houses (59.5%). The occupants of semidetached/town house (low-rise) dwellings hold more post-graduate qualifications (44.9%), Figure 5.47.

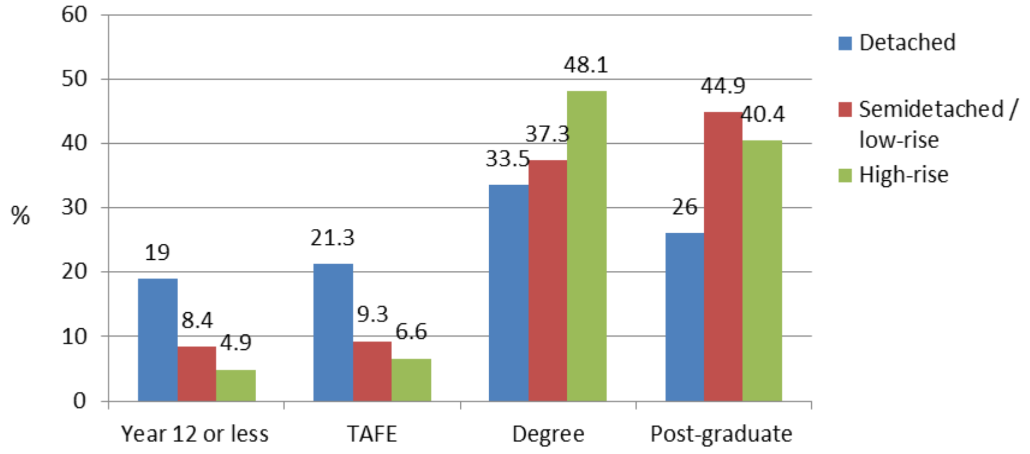


Figure 5.47 Educational levels across the three dwelling types.

Q9 Please describe your occupation.

The majority of respondents across all three dwelling types describe themselves as professional, Figure 5.48. More specifically, the respondents from semi-detached/low-rise dwellings have a higher percentage than from high-rise (67.8%) and detached (59.2%). The respondents from detached dwellings have the highest percentage of retired occupants (20.4% comparing to 11.1% and 7.1%, respectively) and high-rise occupants have the highest percentage of students (12% compared to 2.9% and 3.1%, respectively).

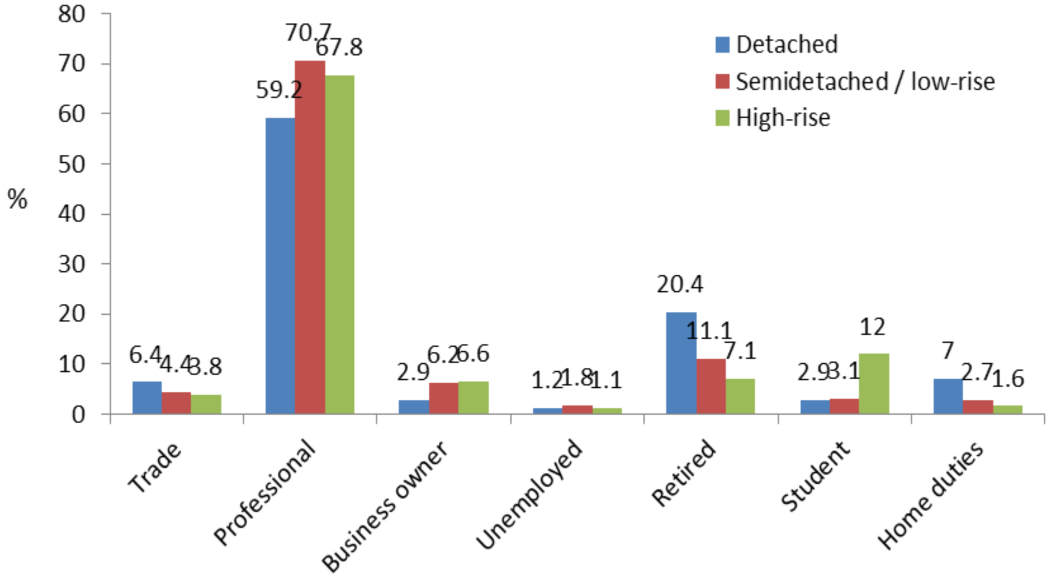


Figure 5.48 Occupations across the three dwelling types.

Q10 How do you currently dispose of your food waste?

□ *Council provided garbage bin* □ *Council provided Green bin*

□ *Home composting* □ *Garbage chute*

The detached household has more options for HFW disposal than the other two dwelling types and this is reflected in the data, Figure 5.49. Notably, semidetached/low-rise dwellings utilize the garbage bin (87.1% more than detached dwellings 57.4%). This could reflect the fact that these dwellings do not have access to a useable back yard where composting or other disposal methods can be carried out. A garbage bin combined with a green bin, home composting and other methods (such as animal feed, an anaerobic digestion tank in the backyard etc.) are all used by one or more of the detached dwellings. The responses from the high-rise dwellings show only one option of the garbage chute, as expected. Semidetached/low-rise dwellings have similarities to detached dwellings but with fewer options. Thus "other" is apparently not a consideration for low- or high-rise dwellings.

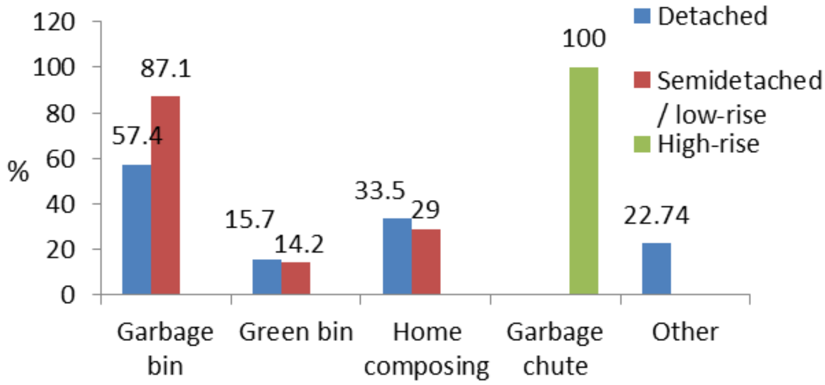
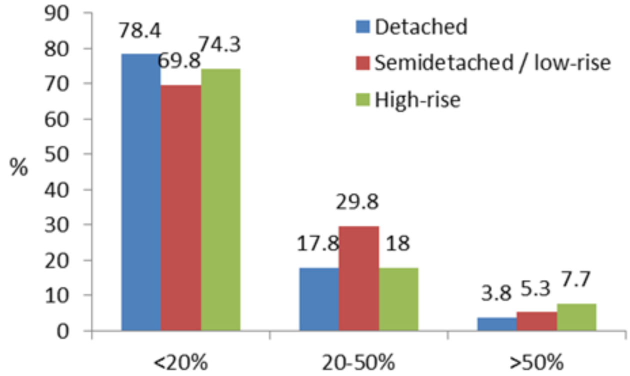


Figure 5.49 Current disposal methods for HFW across the three dwelling types.

Q11 Please provide an estimate of the percentage of food waste in your garbage bin per day? □ *<20%* □ *20 – 50%* □ *>50%*

Notably, a large proportion of respondents across all three dwelling types reported less than 20% of food waste in their garbage, Figure 5.50. This would suggest that frequent centralized waste collection would not be the most efficient management technique, arguing for a more decentralized continuous method.



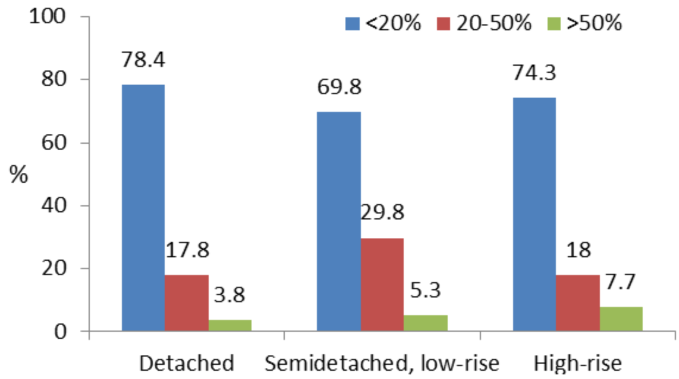


Figure 5.50 Estimates of the percentage of HFW garbage per day across the three dwelling types.

Q12 Please provide an estimate of the percentage of each of the following components of your food waste.

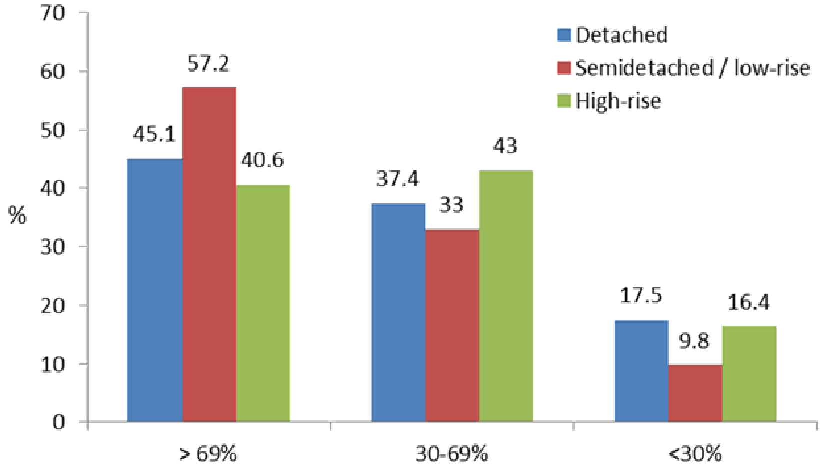
Fruit and vegetable___% bread/pasta/other carbohydrates___% meat/bone/seafood ___%

The responses to this question have been summarized in Table 5.11 and Figure 5.51.

Table 5.11 An estimate of the percentage (%) of each of the three components in HFW with respect to the three dwelling types

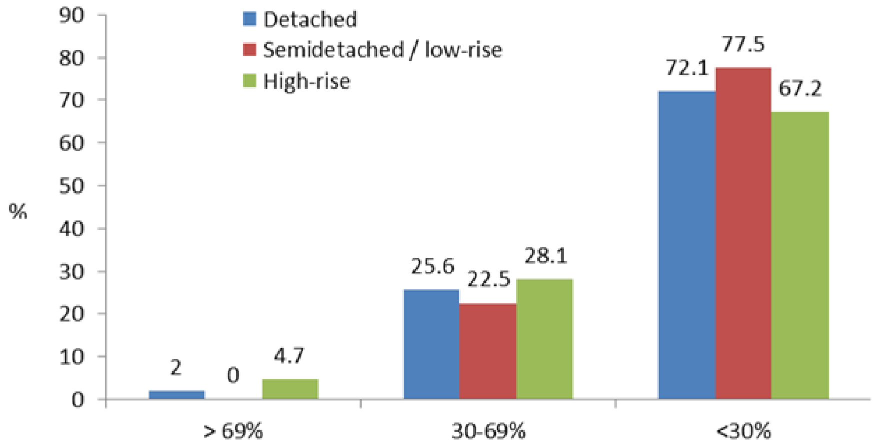
Range of the % breakdown	Fruit and vegetable			Carbohydrate type			Meat / seafood		
	Detached	Semidetached / low-rise	High-rise	Detached	Semidetached / low-rise	High-rise	Detached	Semidetached / low-rise	High-rise
> 69%	45.1	57.2	40.6	2	0	4.7	4.7	4.6	3.1
30-69%	37.4	33	43.0	25.6	22.5	28.1	22.2	24.3	33.6
<30%	17.5	9.8	16.4	72.1	77.5	67.2	72.7	71.1	63.3
Total average	58	64.5	55.5	17.8	15.4	21.1	19.7	20.1	23.3

(a)



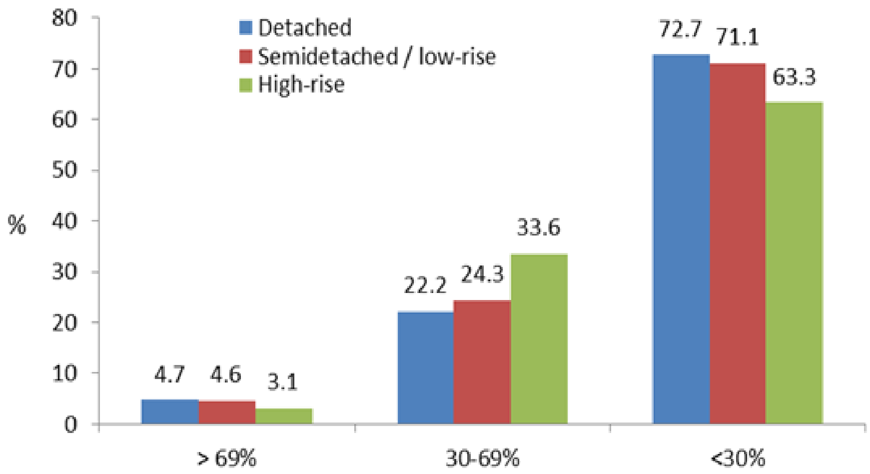
Fruit and vegetable

(b)



Carbohydrate

(c)



Meat and seafood

(d)

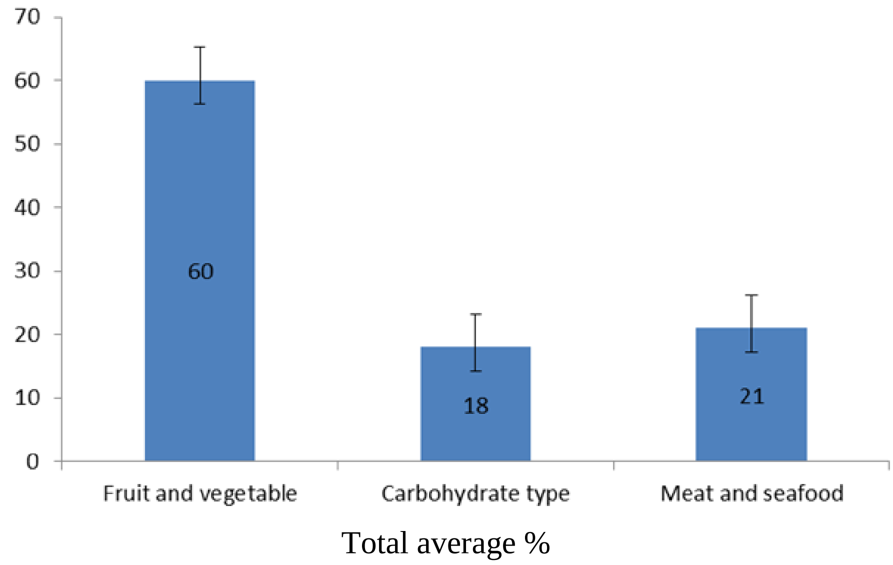


Figure 5.51 A detailed breakdown of the three components in HFW with respect to the three dwelling types, namely (a) fruit and vegetable (b) carbohydrate (c) meat and seafood (d) the average percentage (%) with respect to all dwellings.

Generally, the proportions of food components are similar across the three dwelling types. Thus, from Figure 5.51(d), it can be seen that the fruit and vegetable component at 60 ± 4% is considerably higher that either the carbohydrate component at 18 ±3% or the meat and seafood component at 21 ±2 %.

s data is important for the design of methods and equipment for the treatment of food waste, since the type of food waste will have different decomposition characteristics, especially with respect to such factors as biogas generation. Thus, these figures are important for the on-site treatment unit design and operation in the later part of this thesis.

Q13 Are you willing to separate your food waste from your other waste?

From Figure 5.52, the response to this question can be seen to be overwhelmingly positive, ranging from 90.7 to 97.8%. Of those who are not prepared to do this, the highest proportion are those in high rise dwellings. This is, perhaps, not surprising since these respondents would see fewer alternatives for food waste disposal other than a chute. With appropriate on-site technology that provides some positive benefit (such as biogas generation), such residents might be more motivated in this regard.

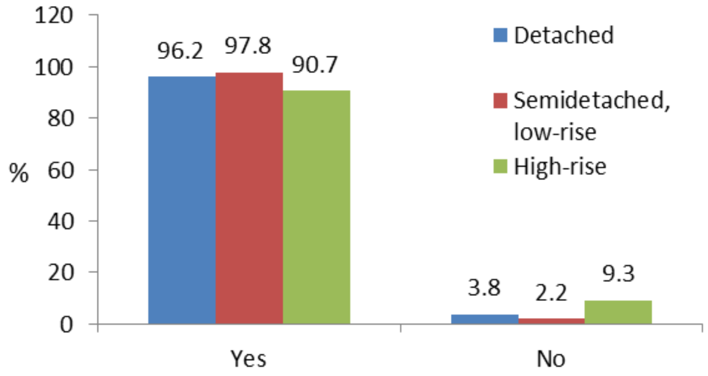


Figure 5.52 Willingness to separate the components of HFW across the three dwelling types.

Q14 Ideally, what treatment would you prefer for your food waste?

□ *Composting bin in backyard*

□ *Disposal to garbage bin/chute*

□ *Treatment at your kitchen sink - combined with appropriate technology to process the waste*

□ *Other (please specify)*

The results in Figure 5.53 are as expected and very encouraging in the sense that those in low and high-rise dwellings are supportive of on-site appropriate technology.

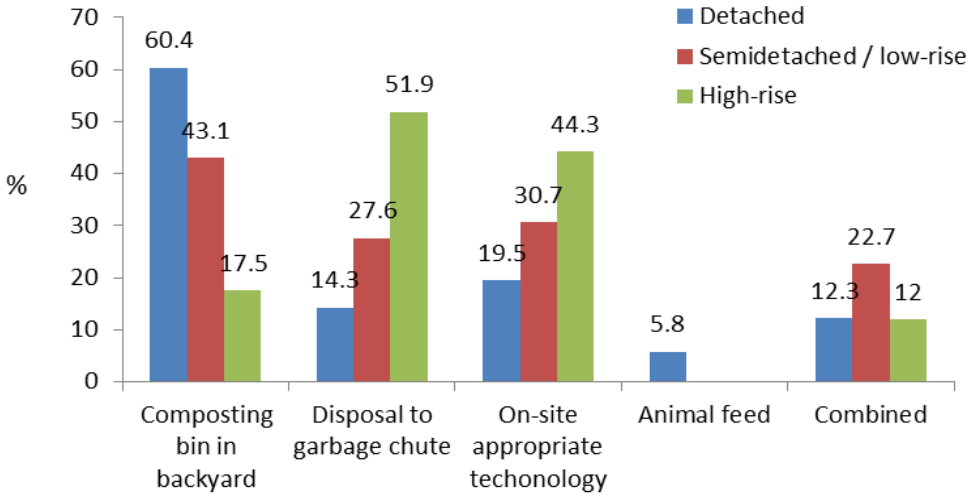


Figure 5.53 The preferred HFW treatment across the three dwelling types.

Q15 What is most likely to motivate you to segregate your food waste (rank from 1 to 6, 1 being the most likely)?

Council regulation____ Peer pressure____ Economic benefit____ Availability of separating and disposal technology____ Environmental reasons___ Cleanliness/hygiene____

From these results, Figure 5.54, environmental reasons score very highly across the three dwelling types. Notably, the availability of separating and disposal technology rates very highly with both low rise and high-rise occupants, especially the latter. Whilst the other categories are of moderate importance, the least important across all dwelling types is peer pressure. These results further support the development and implementation of appropriate on-site technology.

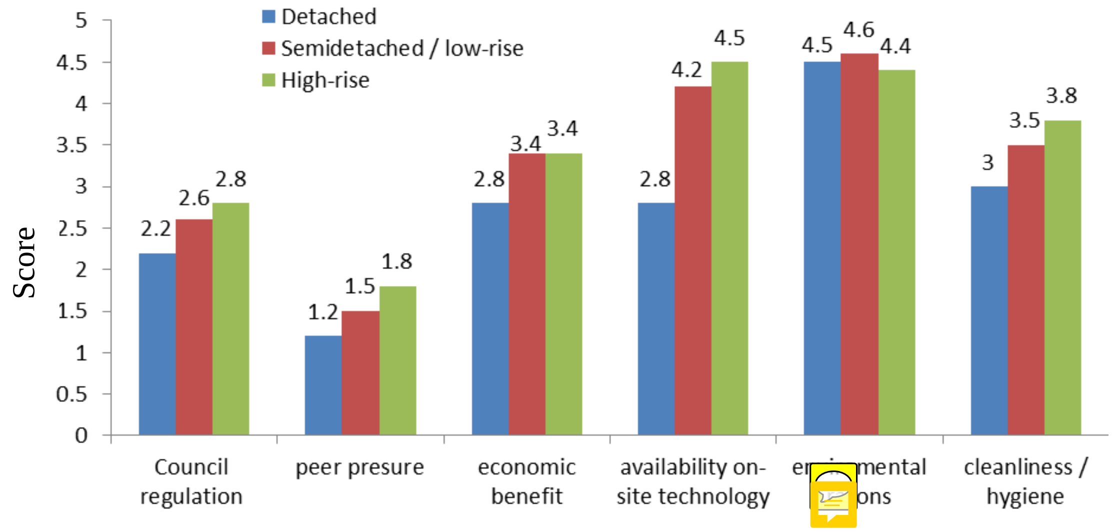


Figure 5.54 Motivation for segregation of HFW from other waste across the three dwelling types.

Q16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations (1 – 'not important', 5 – 'highly important')?

Q17 Do you and/or your family support the availability of environmentally friendly practices and technologies (1 - 'do not support', 5 – 'highly support')?

Q18 To what extent are you aware of environmental regulations relating to waste disposal (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')?

The responses to these questions are shown in Figure 5.55. Across the three dwelling types, the day-to-day environmental impact of individuals and subsequent generations is considered to be highly important. Similarly, the availability of environmentally friendly practices and technologies is rated very highly across the three dwelling types. The extent of awareness of environmental regulations to waste disposal is not so high overall but is more for those in detached dwellings. This could be due to the more contact that such residents have with waste management processes.

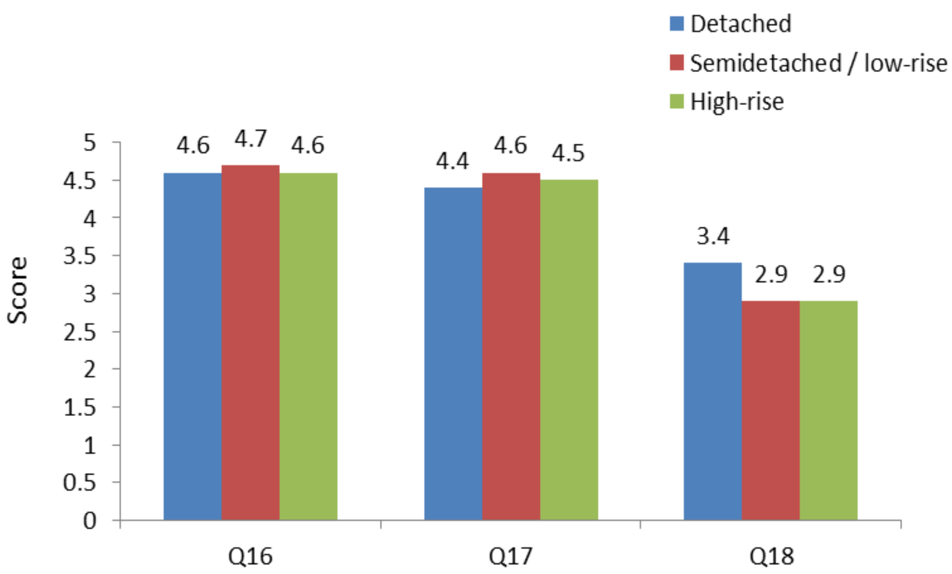


Figure 5.55 Average responses to Q16, Q17 and Q18 respectively left to right across the three dwelling types.

5.4 Conclusions

This survey has investigated the attitude of residents toward HFW management from three dwelling types that cover three geographical regions within the Melbourne metropolitan area. 751 responses were obtained from more than 103 postcodes. Many of the conclusions from this survey are embodied in the above Results and Discussion. However, over the three dwelling types, some of the more general observations are worthy of mention as follows:

- The demographics as reflected by the survey (such as family size versus dwelling type, educational levels, occupation etc.) is consistent with the 2016 Census and other data provided by the three councils *and this serves to validate the survey overall.*

- The proportions of HFW that are fruit and vegetable, carbohydrate and protein are 61%, 18% and 21% respectively. Such information is critical for the design and optimization of an onsite biogas generating pilot plant.

- It is apparent that the garbage bin/chute are currently the major HFW disposal method; with high-rise using 100% chute.

- Over 91% of responses are willing to separate their HFW from other household waste. This is a very encouraging outcome and justifies continued research in this area.

- When comparing the six factors that are most likely to motivate a household with respect to the segregation of HFW, the availability of new technology is considered most favourably with the highest score being from high-rise residents.

- In response to the survey question: "Do you have any suggestions on what your local council can do with domestic food waste that might benefit your family and community?" - the responses were, education (13%), promotion of new technology (36%), provision of free FW bins (33%), financial incentives from council to households that use environmentally friendly technology (5%) and reinforcement of new HFW management regulations (8%). Notably, the promotion of new technology scored the highest.

5.5 Possible Implications

During the course of designing and implementing this survey, the complexity of the task became apparent. The design and implementation of such a complex survey, as represented in Figure 5.7, will provide useful guidance for future enquiry. Of the four different methods employed in collecting responses (R1 – R4), the face-to-face method at a Council community event, R1, achieved the highest success rate, even in the absence of a prize incentive. The next most successful involved accessing the website for one of the collaborating Councils, R2, with a prize incentive; this enabled all those with access to this site to conveniently respond. In this regard, Figure 5.56 provides some useful information on the time it takes for residents in R2 to respond to the web-based survey. These methods emphasize that Council involvement and collaboration is absolutely vital. The surveys of high- and low-rise residents, R3 and R4, respectively, proved to be the most difficult in terms of response rate, even though the same prize incentive was offered. Both of the latter surveys involved the actual delivery of the flier to the resident via mail-box drop. It may be that this latter method was perceived by many residents as “junk mail” and, for future surveys, a method for countering this would have to be devised. One such method could involve including an official Council logo on an envelope containing the flier – with Council permission. This research was unable to achieve this on this occasion. The lower response rates of R3 and R4 could also be related to the time lapse involved in delivering the flier and the resident accessing the nominated website. However, such data for R 3 and 4 was not available. It was also difficult to obtain information on the occupancy rate of the high-rises and this need to be pursed further.

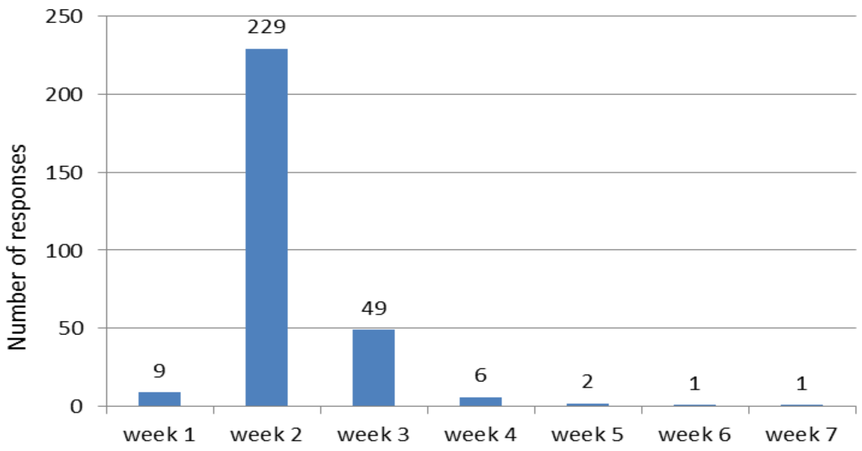


Figure 5.56 Number of response distribution within seven weeks within the first online survey (Run 2)

5.6 References

.id - the population experts 2019, *Australia community profile*, viewed 4th of Feb. 2019, <https://profile.id.com.au/australia/household-size>.

Andersen, JKB, A.; Christensen, T. H.; Scheutz, C. 2010, 'Greenhouse gas emissions from home composting of organic household waste', *Waste Management*, vol. 30, no. 12, pp. 2475-82.

Cherubini, FB, S; Ulgiati, S 2009, 'Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration', *Energy*, vol. 34, no. 12, pp. 2116-23.

Cherubini, FS, A. 2011, 'Life cycle assessment of bioenergy systems: State of the art and future challenges', *Bioresource Technology*, vol. 102, no. 2, pp. 437-51.

Chiew, YLS, Johanna; Baky, Andras; Hansson, Per-Anders; Jönsson, Håkan 2015, 'Environmental impact of recycling digested food waste as a fertilizer in agriculture—A case study', *Resources, Conservation and Recycling*, vol. 95, pp. 1-14.

Clift, R, Doig, A & Finnveden, G 2000, 'The Application of Life Cycle Assessment to Integrated Solid Waste Management', *Process Safety and Environmental Protection*, vol. 78, no. 4, pp. 279-87.

Ellen MacArthur Foundation 2015, *The circular model brief history and schools of thought*.

Ellen MacArthur Foundation and McKinsey & Company 2014, *Towards Circular Economy: Accelerating the scale-up across global supply chains*, World Economic Forum, Geneva, Switzerland.

Ermolaev, ES, C.; Pell, M.; Jonsson, H. 2014, 'Greenhouse gas emissions from home composting in practice', *Bioresour Technol*, vol. 151, pp. 174-82.

Hertwich, EG 2005, 'Life Cycle Approaches to Sustainable Consumption: A Critical Review', *Environmental Science and Technology*, vol. 39, no. 13, pp. 4673-84.

Hill, ALD, O L; Andersen, F M 2014, 'Modelling Recycling Targets: Achieving a 50% Recycling Rate for Household Waste in Denmark', *Journal of Environmental Protection*, vol. 2014.

Hoefnagels, RS, Edward; Faaij, André 2010, 'Greenhouse gas footprints of different biofuel production systems', *Renewable and Sustainable Energy Reviews*, vol. 14, no. 7, pp. 1661-94.

Lofgren, Oea 2015, *Waste management and sustainable consumption - reflections on consumer waste*, Routledge, New York.

Mason, LB, T; Fyfe, J; Smith, T; Cordell, D 2011, *National food waste assessment-final report*, Institute for Sustainable Futures, UTS.

Matsakas, L & Christakopoulos, P 2015, 'Ethanol Production from Enzymatically Treated Dried Food Waste Using Enzymes Produced On-Site', *Sustainability*, vol. 7, no. 2, pp. 1446-58.

Meadows, HR, J.; Meadows, LD 2004, *The limits to growth : the 30-year update*, White River Junction, Vt : Chelsea Green Publishing Company, US.

Messina, A 2012, *Sustainability measurement handbook*, Delhi : University Publications; 1st ed.

Mirabella, NC, Valentina; Sala, Serenella 2014, 'Current options for the valorization of food manufacturing waste: a review', *Journal of Cleaner Production*, vol. 65, pp. 28-41.

Monier, VM, S; Escalon, V; O'Connor, Clementine; Anderson, Gina; Montoux, Hortense; Reisinger, Hubert; Dolley, Phil; Ogilvie, Steve; Morton, Gareth 2010, *Bio food waste - final report*, Euopean Commission.

Palmer, P 2004, *Getting to Zero Waste*, Purple Sky Press.

Pham, TK, R; Parshetti, G K.; Mahmood, R; Balasubramanian, R 2015, 'Food waste-to-energy conversion technologies: Current status and future directions', *Waste Management*, vol. 38, no. 0, pp. 399-408.

Ren, Y, Yu, M, Wu, C, Wang, Q, Gao, M, Huang, Q & Liu, Y 2018, 'A comprehensive review on food waste anaerobic digestion: Research updates and tendencies', *Bioresource Technology*, vol. 247, pp. 1069-76.

Romero-Güiza, MSP, M.; Astals, S.; Benavent, J.; Valls, J.; Mata-Alvarez, J. 2014, 'Implementation of a prototypal optical sorter as core of the new pre-treatment configuration of a mechanical–biological treatment plant treating OFMSW through anaerobic digestion', *Applied Energy*, vol. 135, pp. 63-70.

Sibrian, R, Komorowska, J & Mernies, J 2016, *Estimating houseld and institutional food wastage and losses- measuring food deprivation and food excess in the total population*, Food and Agriculture Organization of the United Nations.

Statistics, ABo 2016, *2016 Census QuickStats*, , Australia Bureau of Statistics, viewed 4 of Feb. 2019, <http://quickstats.censusdata.abs.gov.au/census_services/getproduct/>.

Tonini, D & Astrup, TF 2013, 'Environmental assessment of energy production from waste and biomass', Technical University of DenmarkDanmarks Tekniske Universitet, AdministrationAdministration, IT ServiceAfdelingen for IT-Service.

Vandermeersch, TA, R. A. F.; Ragaert, P.; Dewulf, J. 2014, 'Environmental sustainability assessment of food waste valorization options', *Resources, Conservation and Recycling*, vol. 87, no. 0, pp. 57-64.

Zaman, AU 2010, 'Comparative study of municipal solid waste treatment technologies using life cycle assessment method', *International Journal of Environmental Science & Technology*, vol. 7, no. 2, pp. 225-34.

Chapter 6: Current food waste anaerobic digestion processes and technology

6.1 Introduction

Chapter 2 discussed the comparative advantages of AD, demonstrating its potential across a range of areas including; waste treatment and management, energy efficiency, environmental and economic outcomes for domestic food waste management applications. The findings have been documented by (Ariunbaatar, 2014) and in numerous other studies on organic waste treatment. The amount of food waste generated from consumption - the last segment of the food waste generation chain, is consistently reported in the literature as being the largest; namely, up to 25.5%, compared to 17.5%, 3.8%, and 3.4%, respectively, from production, processing/packaging and distribution/marketing (Xu et al., 2018). If combining the FW occurred at the retail and consumer levels of consumption, this figure is up to 40% of the total food production. This percentage is distributed fairly evenly between developing and industrialized nations (Curry and Pillay, 2012). The survey results (see Chapter 4 and 5) demonstrated that the development and promotion of AD's through technological and product innovation, has immediate application at the household level and will consequentially be an important part of managing the HFW of urban sustainability.

With FW comprising 80-97% of the volatile solid (VS)/total solid (TS) ratio, water comprising 70-90% of total weight and a carbon to nitrogen ratio (C/N) of 14.7–36.4 (Zhang et al., 2014, Zhang et al., 2007), FW is ideally suitable as a substrate for AD. Traditional FW disposal to landfill has been banned in most countries and there are disadvantages with other treatments such as incineration or gasification, due to the high moisture content (MC) and air pollution. The usage for animal feed is also a problem due to the risk of disease. More recently, AD treatment has become an environmentally friendly and, in some cases, an economically beneficial choice for the waste treatment industry.

In the case of AD technology, there are a significant number of outstanding issues that need to be considered including a long start-up/process time (Leung and Wang, 2016) and the methane production rate. For small-scale anaerobic digesters there remains several major challenges. There are a number of smaller-scale AD reactor units in operation, but they are mainly installed in rural areas because of longer processing times (over 40 days). However, as noted in the conclusion of Chapter 2, HFW, on-site, small scale, AD technology can be beneficial via a reduction in environmental impact and cost of collection, sorting and transportation - and from the possibility of turning the waste into energy or fertilizer on site. On-site AD has the potential of achieving "zero waste" in a micro circular economics (MCE) context as it can potentially close the loop of food production, *vide supra.* Also, on-site treatment and utilization can result in a reduction in current waste recycling market complexity (De Clercq et al., 2017). To address these concerns, on-site HFW AD digesters are certainly encouraged.

In order to develop a suitable on-site FW AD reactor, we need to fully understand the relevant HFW characteristics, the AD processes and existing relevant AD treatment technologies that are applicable to FW. This chapter overviews the major issues in regard to the FW's AD processes and the relevant technology.

The characteristics of FW are complex and determined by a wide range of factors. For example, they are commonly classified in terms of physicochemical and biochemical data, nutritional elements, elemental composition and heavy metal content (Fisgativa et al., 2016). Fisgativa stated that the characteristics of FW are also heavily dependent on factors such as geography and season. Various parameters that are important include pH (acidity), BMP (Biochemical Methane Potential), DM (Dry Matter), VS (volatile solids), CEL (cellulose), C, O, and TAN (total ammonia nitrogen), that are all also influenced by the method and source of collection. For example, the C, N and C/N ratio are influenced by season as found in the results from 102 samples taken from Asia (42%), North America (15%) and the European Union (43%) (Fisgativa et al., 2016). However, there are some general characteristics of FW including the fact that FW has the highest acid reading (average of 5.1) compared to other organic wastes used in AD, such as green waste, cattle manure and sewage sludge (average of 7.3, 8.7 and 7.8, respectively). FW also has a higher BMP (average of 460.0 NLCH4/kg VS) compared to cattle manure and sludge sewage (average of 250 NLCH4/kg VS and 27

NLCH4/kg VS, respectively). The TS and VS of FW vary widely depending on the calculation methodology. These studies show that TS had a range of 7.0 to 30.9 % WM (% of total wet mass weight) (Zhang et al., 2007, Zhang et al., 2014); VS had range of 17.10 to 26.35 %WM (Zhang et al., 2014) or 80 to 96.4 % DM (% of total dry mass weight) (Fisgativa et al., 2016, Guo et al., 2011). The carbon to nitrogen ratio (C/N) ranges from 12.6 to 36.4 (Zhang et al., 2007, Guo et al., 2011, Fisgativa et al., 2016).

Sufficient AD research has been done on single feedstock, including algal biomass from straw, olive pomace, milk whey, cellulose, wastewater sludge (Montingelli et al., 2015) and animal manure from agricultural and other waste processes (Zhang et al., 2016). Recent research has shown that co-digestion of two or more different feedstocks can reduce inhibition of the digestion process by balancing the pH and the C/N ratio (Zhang et al., 2016), therefore increasing the methane production. However, due to the complex composition of food waste, research into the AD of FW, especially with respect HFW, is still rare (Guo et al., 2011).

Differences in the composition of HFW across continents, countries and location of residents are listed in Table 6.1. These can be seen to be very variable.

Table 6.1 FW composition (%) in some countries of EU (Heaven et al., 2010), Asian (Zhang et al., 2007, Guo et al., 2011) and Great Melbourne[18]

% wet weight	UK	Finland	Portugal	Italy	China	Korean	Great Melbourne
Fruit and vegetable	60.9	44.5	59.2	69.0	38.2	67.5	61
Carbohydrate	10.5	4.2	3.3	15.2	38.6	12.5	18
Protein	8.4	6.3	8.03	7.6	17.3	17.5	20.5
Mixed/other meals	12.5	14.3	29.0	8.3	5.9	2.5	0.5

A variety of FW's compositions have been reported to show different methane yields. Researchers have shown that cooked meat, boiled rice, fresh cabbage and mixed food wastes, produce 482, 294, 277, and 472mL/gVS, respectively, which translate to 82%,

[18]FW composition in EU is reproduced from HEAVEN, S., ZHANG, Y., ARNOLD, R., PAAVOLA, T., VAZ, F. & CAVINATO, C. 2010. Compositional analysis of food waste from study sites in geographically distinct regions of Europe. *Biowaste as feedstock for 2nd generation.* Seventh cooperation. And the data of Greater Melbourne is from Chapter 5, which is the results from surveys.

72%, 73% and 86% of the stoichiometric methane yield under mesophilic conditions. There is, however, little information on thermophilic AD of FW (Zhang et al., 2007).

6.2 Anaerobic digestion (AD)

Anaerobic digestion (AD) is a biological treatment that generates biogas. Given the commercial significance of AD it is not surprising that the process has attracted interest in research and investment from a variety of industries over the last few decades. The AD process involves the breakdown of organic matter by microorganisms in the absence of oxygen, resulting in the production of biogas. There are four processes that are central to commercial scale production including; biodegradable waste separation, contaminant removal, homogenisation pre-treatment, biogas generation by anaerobic digestion and residue post-treatment (Kosovska, 2006). While AD has made modest efficiency gains, issues remain at a technical and production level with reactions times and methane production being ongoing constraints which has been described previously.

6.2.1 The AD process

The biogas generated from FW through anaerobic digestion includes four main stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis, as descripted as Figure 6.1.

The first stage is where hydrolytic bacteria endowed with amylases, lipases, proteases and celluloses break down polymers to monomers.

The second stage involves the use of fermentative bacteria to convert hydrolysis products into volatile fatty acids, alcohols or directly into acetate, carbon dioxide and hydrogen,

The third stage is acetogenesis which involves the use of syntrophic acetogen to convert VFA into acetate, carbon dioxide and hydrogen through syntrophic acetate oxidation or homoacetogenesis.

In last stage of methanogenesis, acetate, carbon dioxide and hydrogen from acetoclastic and hydrogenotrophic methanogens are converted into the final products of methane, carbon dioxide and trace gases (Manyi-Loh et al., 2013).

During these stages, the composition of feedstock, the pH, temperature, nutrient level, C:N ratio within the digester and operation method all contribute to the production of methane (Tampio et al., 2014, Zhang et al., 2014). In the following sections each of the relevant issues will be discussed individually.

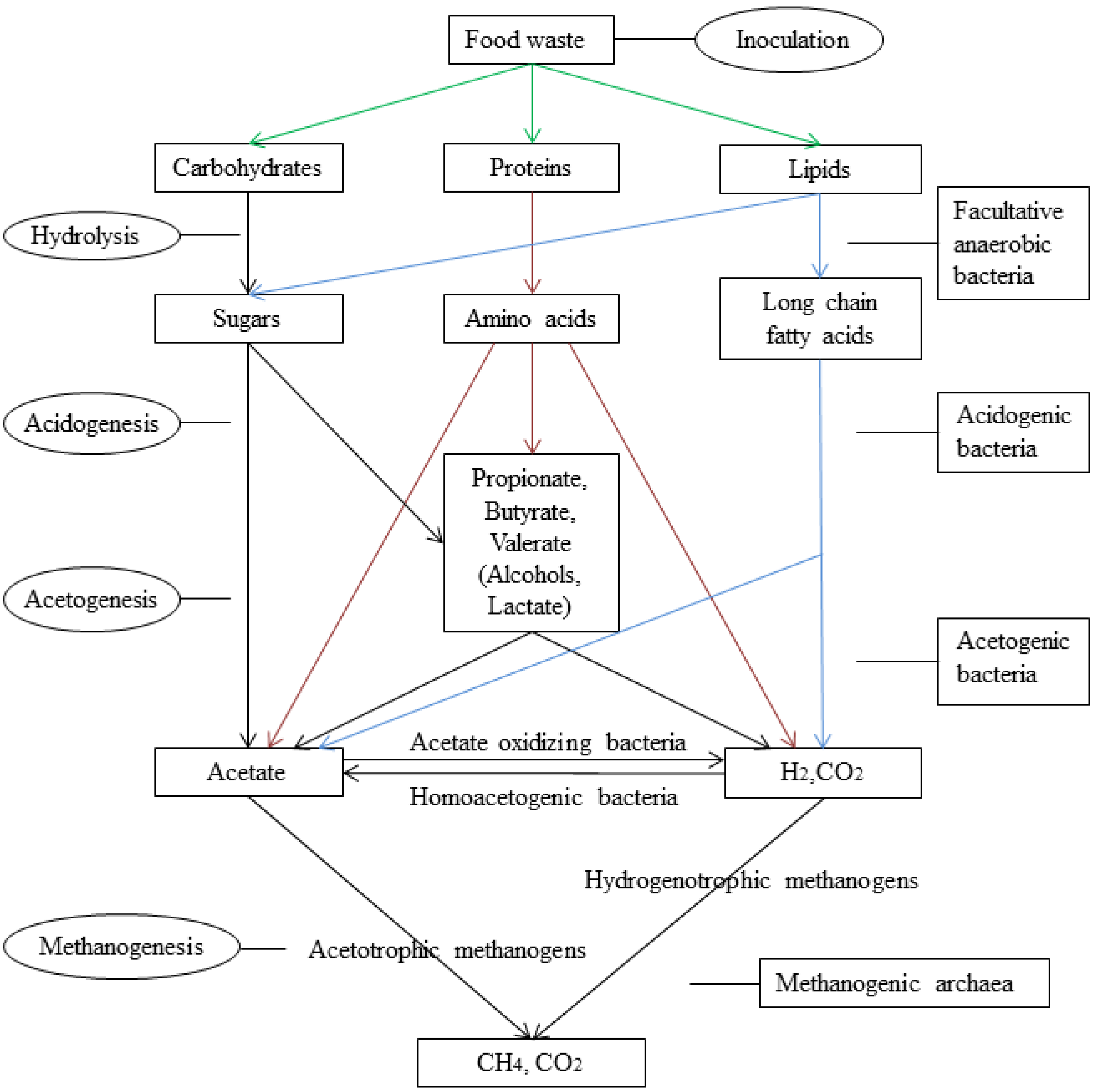


Figure 6. 1 Food waste anaerobic digestion process: main steps and relevant microbiota (Wang et al., 2018)

6.2.2 AD microorganisms

Figure 6.1 shows that the AD of FW biochemical process and microorganisms play a major role during this process. Microbial methanogenic organisms involve a number of metabolic pathways involving carbohydrate utilization, fatty acid degradation, amino acid fermentation and syntrophic acetate oxidation (Campanaro et al., 2016). AD includes four different but interconnected metabolic pathways comprising hydrolysis, acidogenesis, acetogenesis and methanogenesis. Biogas microorganisms can be subdivided according to three metabolic pathways including : (i) hydrolysis, (ii) volatile acid fermentation, and (iii) methane formation ((USEPA), 2006). Within the first and second stages of AD process there are up to 50 different bacteria including Clostricdium, *Bacteroides*, *Bifidobacterium and Butyrivibrio*. In the final stage of methanogenesis some 65 microorganisms have been identified, including into 3 orders, 7 families and 19 genus (Jilin University, 2017), which all belong to the domain Archaea[19].

The microbial organisms, metabolic activity and metabolic pathways of the AD system are influenced by its VFAs, ammonia nitrogen and pH (Guo et al., 2011). Once the incubation conditions stabilize, they are reported to comprise a complex interdependent food web (Gavala et al., 2003). However, research on the relationship within the microbial community and their performance in AD has not been widely reported, especially for FW scenarios (Kim et al., 2017).

For methanogens, which are characterised as anaerobic archaea, the community structure, functioning and supplies of substrates are all directly or indirectly affected by the temperature (WU et al., 2014；Ding，Weixin, 2003 #1596). Methanogens can also be divided into four categories – psychrophiles (<25^{o}C), mesophiles (~35^{o}C), thermophiles (~55^{o}C) and hyperthermophiles (>80^{o}C), as determined by differences in optimum temperatures. In the case of methanogenesis, the methane product is generated from acetic acid (about two-thirds of the total methane product), H_2/CO_2 (about one third) and C-1 compound (only small amount). Within these four categories, psychrophiles are produced mainly through the acetic acid metabolic pathway; metabolism is dependent on both acetic acid metabolism and H_2/CO_2 reduction pathways and thermophiles/hyperthermophile (>80C^{o}) but only through the H_2/CO_2 reduction pathway (WU et al., 2014, Wang et al., 2014).

Within the AD process, the main microorganisms that play a role in the production of methane are *Methanobacterium, Methanobrevibacter, Methanococcus, Methanosarcina*

[19] https://en.wikipedia.org/wiki/Methanogenesis

and *Methanosaeta* (Wang et al., 2018). These are commonly known as the methanogen communities and their typical pH and temperature conditions in a FW/AD process are listed in Table 6.2.

Table 6.2 The optimum pH and temperature of microorganisms involved in FW/AD

Methanogen communities	mean and range of optimum pH	mean and range of optimum temperature (°C)	Common substrates *	Reference
Methano-bacterium	7.1 (5.6-8.6)	36 (28-65)	H_2/CO_2 (H_2/M, 2P, 2B)	(Wang et al., 2018, Wang et al., 2014, CHENG, 2016)
Methanobrevi-bacter	7.1 (6.0-7.8)	36 (30-55)	H_2/CO_2 (F/CO_2)	(Lee et al., 2014, CHENG et al., 2016)
Methanosaeta		35		(Wang et al., 2014)
Methanosarcina	6.9 (6.5-7.8)	35 (25-55)	M (H_2/CO_2, CO, A, Ms MT, D)	(Guo et al., 2014, CHENG et al., 2016)
Methanothermo-bacter	7.3 (6.8-8.1)	63 (55-70)	H_2/CO_2 (F)	(Li et al., 2015b, CHENG et al., 2016)
Methanculleus	7.0 (6.5-8.1)	39 (23-55)	H_2/CO_2 (F, 2P, 2B, CP)	(Lin et al., 2012, CHENG et al., 2016)

*: The letters in lines represent as following, A: Acetate; CP: Cyclopentanol; D: Dimethylsulfide; F: Formate; M: Methanol; Ms: Methylated amines; MT: 2B: 2-Butanol; 2P: 2-Propanol.

6.2.3 Factors and parameters that influence the AD process

As indicated in the last section, temperature, VFAs, ammonia nitrogen, pH, OLR and C:N ratio are the primary factors which influence the microbial community structure, metabolic activity and metabolic pathway of the AD system. These are discussed below.

6.2.3.1 Temperature

Temperature has a significant influence, not only the microbial community composition and the activity of enzymes and co-enzymes, but also the methane yield and digestate (effluent) quality (Vanwonterghem et al., 2015, Zhang et al., 2014). Within the AD process the temperature is normally divided into in four categories: Cryophilic or psychrophilic (< 20 °C), mesophilic (20 – 42 °C) and thermophilic (42 – 70 °C) and hyperthermophile (>80oC)(Leung and Wang, 2016, Ecke and Lagerkvist, 2000).

Mesophilic microbes are more commonly used in sewage sludge treatment (Gavala et al., 2003). Due to mesophilic microbes, metabolic processes can produce methane through both acetic acid metabolism and H_2/CO_2 reduction pathways. Therefore, these are the microbes of choice for the FW/AD process (Table 6.2).

Thermophilic microbes have a kinetic advantage through the hydrolysis of biomass. These microbes can increase the metabolic rate of methanogenesis while at the same time destroying the pathogenic bacteria and reducing odours (Zhang et al., 2014, Kim et al., 2017, Gavala et al., 2003). El-Mashad et al. (2004) demonstrated that a stable thermophilic temperature of 50-60 °C can, together with low VFAs, produce a consistent methane yield (Hartmann and Ahring, 2006, Gavala et al., 2003). These authors also stated that thermophilic processes are 30-50% more efficient in generating biogas when compared with mesophilic processes. Research reported by Micolucci (2015) showed that thermophilic bacteria generated a biogas product rate of 0.9 m^3 biogas/kg TVS and 68.8% a methane content compared to mesophilic anaerobic digestion of 0.79 m^3 biogas/kg TVS and 66% methane content.

However, during hydrolysis, the percentage of hydrolysation is higher at 50 °C than it is at 60 °C. Thermal conditions may, during this stage, result in the carbonisation of biomass. According to Gavala et al. (2003), thermophilic anaerobic microorganisms do result in a rapid increase in VFA concentrations when the substrate is inhibited. It follows, therefore, that additional stabilisation of the process environment is required when operating under thermophilic conditions compared with mesophilic conditions (Zhang et al., 2014).

6.2.3.2 pH and VFAs

Previous studies have shown that pH plays an important role in AD. It is also documented that pH is influenced by VFA and temperature. A higher rate of volatile acid production than methane production is expected during start-up. There are major organic acids (acetic, butyric, propionic and lactic) that form during fermentation. During the aerobic pre-treatment stage, bacteria such as *E.coli* forms acetate acid (Sundberg, 2005). Increasing

VFA results in a decline in pH. An acidic environment has been shown to have a negative impact on the activity of acetoclastic methanogens, which could result in the inhibition of methanogenesis and disruption of the anaerobic process (Brown and Li, 2013). This is attributed to the finding that most anaerobic bacteria, including methane-forming bacteria, only perform well within a pH range of 6.8 to 7.2 (Flanders Health Blog, 2017).

During methanogenesis conversion of acids into ammonium (NH_4^+)/ammonia (NH_3), it has been reported that there is an increase in pH up to 9.24 (at 25°C), resulting in an inhibition of the AD process due to toxic effects on methane-forming bacteria. Therefore, the balance between the VFAs' rate and CO_2 can result in a pH value which is self-buffered (Eckenfelder 2000).

The optimal pH ranges for hydrolysis and acidogenesis, which are two pertinent indicators to evaluate the biological performance of AD, are 5 to 6 and 6 to 7, respectively (Zhang et al., 2017a, Sitorus et al., 2013, Leung and Wang, 2016). The pH varies depending on the amount of CO_2 produced during the biodegradation process. When the pH reaches a value of less than 6.2, the bacteria will cease producing CO_2. VFAs are consumes and alkalinity increases after 5 days (Sundberg, 2005, Flanders Health Blog, 2017), Figure 6.2. The alkali will then buffer the VFAs countering a decrease in pH and maintaining the AD process (Zhang et al., 2005). The optimal pH for methanogenesis is around 7.5 and with this stage the higher pH consumes VFAs with the generation of methane and carbon dioxide.

At pH values below 6 or above 8 the incubation conditions are not favourable due to the toxic influences on methanogenesis (Zhang et al., 2017a, Leung and Wang, 2016). Controlling the pH can increase the solubilization rate and VFA production rate therefore increase the methane yield (Zhang et al., 2005, Sumardiono et al., 2013).

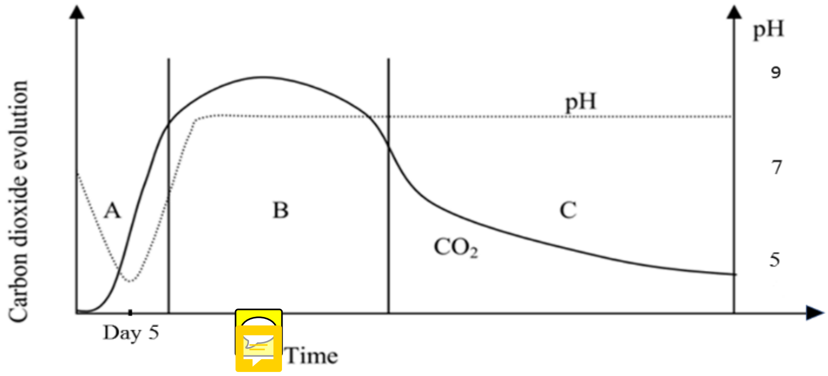


Figure 6. 2 The effect of pH on CO_2 production (the time-span of both B and C phases are from a few days to several months)

Changes in alkalinity provide an important measure of digester efficiency. A decrease in alkalinity can be caused by 1) an accumulation of organic acids following a failure of methane-forming bacteria to convert the organic acids to methane; 2) a slug discharge of organic acids to the anaerobic digester; or 3) the presence of wastes that inhibit the activity of methane-forming bacteria. A decrease in alkalinity usually precedes a rapid change in pH (Flanders Health Blog, 2017).

The alkalinity is the result of an increase in amino groups ($-NH_2$) and production of ammonia (NH_3) arising from the degradation of proteinaceous wastes. Also, thickened sludges have relatively high alkalinity which is due to an increase in the feed rate of proteins.

6.2.3.3 Buffer solution selection

In order to create an optimum environment for sustained methanogenesis during continuous fresh substrate feeding, it is important to stabilise the pH. AD buffer solutions are therefore important for maintaining a stable pH to ensure optimum AD performance (Flanders Health Blog, 2017).

The use of buffers can prevent a rapid change in pH (Flanders Health Blog, 2017). Some chemicals commonly used to maintain the alkalinity are sodium bicarbonate ($NaHCO_3$), sodium carbonate (Na_2CO_3), K^+ salts such as potassium bicarbonate ($KHCO_3$) and potassium carbonate (K_2CO_3) and Ca^{2+} salts such as calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$); and NH_4^+ as anhydrous ammonia (NH_3) (小丽, 2011).

Bicarbonate is considered to be the primary source of carbon for methane-forming bacteria. Conversely, the degradation of organic compounds has been shown to produce organic acids that reduce alkalinity. Sodium bicarbonate and potassium bicarbonate are the better option because of their desirable solubility, handling and minimal adverse impacts within the digester. They are also considered to be less toxic to the bacteria. Sodium bicarbonate and sodium carbonate release carbon dioxide upon addition, whereas sodium nitrate releases molecular nitrogen (N_2) and nitrous oxide (N_2O) upon addition. The release of nitrate ions (NO_3^-) increases the ORP of the digester However, any chemical selected for addition to the digester should be added slowly to prevent any adverse impact on the bacteria due to rapid changes in alkalinity, pH, ionic strength or the Oxidation/Reduction Potential (ORP) (Flanders Health Blog, 2017).

Ammonia reacts with carbon dioxide and water to increase the production of ammonium bicarbonate. Ammonium carbonate, in turn, reacts with volatile acids to increase the production of volatile acid salts. Anhydrous ammonia may produce a negative pressure in the digester by reacting with carbon dioxide. In addition, the increase in pH can lead to an increase in ammonia gas which is toxic at high concentrations (Flanders Health Blog, 2017).

The main factor that results in anaerobic digestion failure or operational difficulties is due to changes in the total ammonia concentration. The literature shows that the inhibition of anaerobic digestion occurs within the range of 650 to 4000 mg/L of NH_3-N (Banksa et al., 2011, Serna-Maza et al., 2015). Indeed, inhibition through high ammonia content is one reason that FW has not been used as a single substrate in AD. However, some reports have indicated that, given a continuous loading process, a stable biogas production system can be achieved even at high ammonia concentrations over extended periods of time.

Therefore, considering the toxicity of the above buffer solutions to methanogenesis, NaOH will be a better option for HFW AD.

6.2.3.4 Total Solids (TS), Total Volatile Solids (TVS) and Organic Loading Rate (OLR)

Both TS and TVS have an impact on the anaerobic digestion system and biogas yield. High TS/TVS rates result in a high organic content. It has also been reported that high lignocellulose levels need longer digestion times and result in low biogas production (Li et al., 2015a).

Previous digestion experiments have shown that the VS (Volatile Solids) levels vary from 65 to 81% (Zhang et al., 2007, Micolucci, 2015)

The Organic Loading Rate (OLR) is one of the important factors that influences the balance of the fermentation process and biogas production during the AD of organic wastes. If the OLR is too high, the AD system can collapse - but if the OLR is too low, it impacts on the economics of the operation. An optimized OLR is therefore essential for the effective and efficient running of an anaerobic reactor (Li et al., 2015a). For example, the methane yield (P) of food waste during anaerobic digestion at two different initial loadings (6.8 and 10.5 gVS/L), at a constant temperature of 50 °C, showed similar results (P=0.303). However, at a setting of 10.5 gVS/L there was a higher daily methane production of 445 mL/gVS compared to 425 mL/gVS for the setting of 6.8 gVS/L - for a digestion incubation of 28 days (Zhang et al., 2007). Zhang (Zhang et al., 2007) stated that there was an 80% yield of methane after the 11th day of digestion. The maximum methane production rate can be up to 602 and 762mL/L.d for settings of 6.8gVS/L and 10.5 gVS/L, respectively, of OLR. In summary, the biogas produced from the digesters at a lower loading had a higher methane content (up to 73% in v/v) compared with the digester that had a higher initial loading.

6.2.3.5 C:N ratio

When the C:N ratio is within the range of 13.0–28.0 the organic mass will be optimum for AD (Romano and Zhang, 2008).

6.3 AD treatment technologies

AD treatment of FW involves a pre-treatment stage, a mid-stage comprising acetogenesis and methanogenesis with methane production and a post-residential treatment stage. Each stage requires a different technology depending on the substrate type, processing specifications and scale of investment. The main technology can be outlined as follows:

6.3.1 Pre-treatment

The main rational for pre-treating substrates for biogas production is to increase the accessibility to the hemicellulose content of the lignocellulosic material (Zhang, C et al. 2014). It includes physical, chemical, biological and combined processes. It is used to determine the rationale process of hydrolysis and acidogenesis (Fig.1). During the hydrolysis and acidogenesis stages, the carbohydrates, proteins, fat and, even cellulose, are converted into glucose, amino acids and long chain fatty acids. During these stages, the oxygen in FW is consumed by facultative anaerobic bacteria after initial degradation by bacteria. The metabolites are then ready to transform into the next stage of acetogenesis. Because the complex heterocyclic compounds and non-desirable volatile fatty acids (VFA) formed in this stage will directly affect the final stage of methanenogenesis (Ariunbaatar, 2014), pre-treatment is important for stimulating the hydrolysis process and improving the nature of metabolites for next stage of AD.

6.3.1.1 Physical pre-treatment

Physical pre-treatment also can be divided into mechanical disruption, temperature and time control.

The non-fibre component of organic waste has been shown to produce a higher methane content when compared to the fibre components of organic waste (Pokój et al., 2015). Reducing the size of particles to 0.8-0.7 mm can also increase the biogas production yield by 28% (Izumi et al., 2010). Therefore, the use of a high shear mixer, grinder and beads mill etc. have been shown to be effective in producing larger size granules of organic waste which will increase the contact between the surface of the substrate and the anaerobic bacteria, thereby resulting in an improvement of the AD process (Esposito et al., 2011, Kim et al., 2000). Alternative treatments such sonication, lysis-centrifuge, liquid shear, collision, high-pressure homogenization, maceration and liquefaction have also been used.

The sonication method uses 20-40 kHz frequency sound waves to reduce the particle size by disrupting the cell structure and the floc matrix - which can increase biogas production by 24-140% and 10-45% for both batch systems and continuous or semi-continuous system, respectively (Chu et al., 2002, Carrère et al., 2010). High-pressure homogenizers (HPH) induce a strong negative pressure within the cell which results in disruption of thecell membrane. As a result, the concentration of soluble protein, lipid and carbohydrate will increase, leading to an increase in biogas production and a decrease in residuals (Hendriks and Zeeman, 2009, Engelhart et al., 2000). Other methods have also been used to disrupt cellular structure in order to accelerate the digestion process and to increase the biogas production. Because of the advantages of mechanical pre-treatment, which includes a reduction in energy use, it has been widely used in AD processes. Thermal pre-treatment of substrates, including heating from 50 to 250 ° C,has been widely used at the industrial scale because it has the direct advantage of increasing the solubility of organic matter and eliminating pathogens (Ariunbaatar, 2014). However, when higher temperatures exceed 150 ^{o}C, an agglomeration of carbohydrates and amino acids has been reported to occur, which inhibits the AD process (Carrère et al., 2010). When a lower temperature of 70 ^{o}C is used, it has been reported that there is an enhancement of methane production, especially when a higher content of carbohydrates is used (Gavala et al., 2003, Ferrer et al., 2008, Rafique et al., 2010, Climent et al., 2007). Increasing the treatment time is also reported to increase the hydrolysis and acidogenesis process, which results in an increase in methanol production by 21-31% (Zhang et al., 2015).

6.3.1.2 Chemical pre-treatment

Chemical pre-treatment utilises oxidants, acids or alkali to treat organic compounds and can result in an increase the methane yield. Papa Papa et al. (2015) reported that using chemical pre-treatment can result in a 11.1% - 16.3% higher yield when compared with using hot water on crops like corn. Wang (2011) demonstrated that chemical pre-treatment of sugar beets/sugar beet leaves and straw can increase methane yield up to 68% and 102%, respectively. However, Wang also stated that chemical pretreatment is not appropriate for carbohydrate-rich and easily degradable substrates because the VFA's rapid accumulation can cause methanogenesis to fail.

Alkali pretreatment is a preferred method used at an industrial scale as AD processes require higher levels pH reading (such as 7.3 for green waste, 8.7 for cattle manure and 7.8 for sewage sludge). During the pretreatment stage the particles of organic matter swell because of solvation and saponification effects, so the surface of the organic matter expands in response to the anaerobic microbes. This effect, in turn, increases the pH leading to an enhancement of AD (Carlsson et al., 2012, Hendriks and Zeeman, 2009).

Acid pre-treatment is mainly used for lignocellulosic substrates. It helps break down the lignin, and the hemicellulose hydrolyses into monosaccharides (Hendriks and Zeeman, 2009). However, the lower pH reading will be result in the inhibition of the AD process. Balancing the pH will, however, lead to an increase in costings.

Ozone pre-treatment: During decomposition, the free radicals of ozone and hydroxyl assist with biodegradation leading to an increase the methane production (Cesaro and Belgiorno, 2013). Ozone pre-treatment has the advantage of not only avoiding chemical residuals, but also has the benefit of disinfecting pathogens (Kianmehr et al., 2010). As a consequence, the use of ozone has become more and more popular in sludge pretreatment.

Previous studies have shown that a number of elements found in FW including sodium, potassium, magnesium and calcium are toxic to propionic acid utilizing bacteria and limit the biogas production. Therefore, in order to avoid the inhibitory effects of these elements in AD during chemical pre-treatment, the salts or cations, and the sodium, potassium, magnesium and calcium ion concentrations must be kept under 5g/L, 8g/L, 720mg/L and 200mg/L, respectively (Kim et al., 2000, Soto et al., 1993, Bashir and Matin, 2004, Chen et al., 2008, Kugelman and McCarty, 1965, Schmidt and Ahring, 1993). FW that contains high levels of cations, trace elements and lignin compounds is less suitable with respect to chemical pre-treatment (Patil et al., 2011).

6.3.1.3 Biological pre-treatment

Biological pre-treatment is a method which involves introducing microorganisms, ammonia nitrogen and organics as enzyme inoculates for both anaerobic and aerobic digestions. Although there are arguments that the hydrolytic-acidogenic procedure is considered a biological pretreatment method (Carlsson et al., 2012), the finding that there is an increase in enzymes from acidogenic microbes (Parawira et al., 2005), has led to the conclusion that the hydrolytic-acidogenic stage is still regarded as a pre-treatment method by most researchers (Ariunbaatar, 2014).

Hu et al (Hu et al., 2015) used the liquid fraction of the digestate as an inoculate, which resulted in a 70.4% increase in biogas production. Parawira et al. (2005) stated that inoculates such as amylase have the highest activity followed by carboxymethyl cellulase and filter paper cellulose.

Many researchers have combined two or three physical, chemical or biological pre-treatments in one process in order to achieve a better energy recovery rate. Thus the rate of methane production from AD has increased significantly, with increases up to 315% being recorded compared to the normal process (Reilly et al., 2015).

6.3.2 Middle stage -- acetogenesis and methanogenesis

Acetogenesis involves two main organisms, acetogen and homeacetogen. The metabolites of VFA, LCFA, alcohols and aromatics are degraded continually by acetogen acetic-acid (CH_3COOH), hydrogen (H_2) and CO_2 which is consumed by homoacetogens (Anderson et al., 2003). Finally, the acetogens under strict anaerobic conditions are degraded into *archaea* form of methanogens.

In view of the importance of acetogenesis in the renewable energy sector, the production of biogas during this stage has been a major focus of AD research. A high number of methods have been undertaken to enhance performance which include procedures for reducing inhibiters, stabilizing the temperature and consideration of the composition of feedstock.

Some techniques that have been used to increase CH_4 production include using 80% N_2 and 20% CO_2 to flush the headspace of the reactor tank (Koch et al., 2015), recycling the effluent, regular additions of cellulolytic organisms and varying the feeding frequency (Manser et al., 2015, Martin-Ryals et al., 2015, Li et al., 2015a).

Chen et al. (2008) listed a number of common inhibitors including ammonia, sulphide, light metal ions, heavy metals and organics that influenced anaerobic inoculation and waste composition. Methods used to mitigate the inhibitory effects from AD reactions include: gas stripping (Serna-Maza et al., 2015, Markou, 2015), polymeric membranes (Díaz et al., 2015), micro aeration (Li et al., 2015c) and chemical oxidization (Bożym et al., 2015).

Stabilizing the temperature and the composition of feedstock can also help the microbial community adapt to the environment.

6.3.3 Methane and post-residential treatment

Biogas from AD is composed of 55 – 70% of CH_4 and 30 - 45% of CO_2. However, biogas from the AD meeds to be purified prior to its use as an industrial fuel. Biogas CO_2 is one of the components that is removed by the photoreactor and gas/liquid transfer unit.

6.4 Digester (AD unit) systems

There are many AD systems which can be divided into single stage and multi stage systems. Traditional small-scale AD systems are mainly single stage systems while the commercial scale units are mainly multi stage systems that include novel digester geometry, solid-state AD, psychrophilic AD and integrated AD systems.

6.4.1 Single stage system

In the single stage system, original mass feeding and anaerobic digestion have been combined in one tank. The continually fed (once a day with 3-8% of TS) of mass can result in wide temperature fluctuations and can lead to poor performance due to incomplete fermentation and decomposition of organic matter - and subsequently low production of biogas. Incomplete decomposition of digester residue results in higher costs for the post-treatment (Nallathambi Gunaseelan, 1997). For that reason, the single stage system has only been used in rural areas or developing countries, where regulation and compliance are not strict.

6.4.2 Multi stage system

Multi stage systems utilize integrated systems and a combination of series configurations to perform multiple functions to produce multi-products during AD treatment. A large amount of multi stage systems are available worldwide. The most common are multi-chambers systems. It has been stated that combinations of biological and thermochemical systems are more efficient in breaking down recalcitrant organic matter. These combined systems can reduce the total digestion time compared to the conventional single-stage digestion, as well as resulting in a higher efficiency of CH_4 production (Hartmann and Ahring, 2006, Nallathambi Gunaseelan, 1997). Other multi stage systems include forward osmosis (Ansari et al., 2015), heat pump systems (Curry and Pillay, 2015), retreating the first residue for further fermentation (Zhong et al., 2015), and hydrogen feeding (Ahern et al., 2015) etc.

Recently, some new innovative technologies in AD have been reported, including the use of H_2 and CO_2 injection systems or membrane bioreactors, which are involved in stabilising the digestion process through buffering and providing a diverse environment for the different stages of the microbial populations (Ahamed et al., 2015, Duda et al., 2015), Gouveia et al. (2015) .

Digester types can be further classified into either wet systems, when it contains less than 10% of total solids, or dry systems, when it contains less than 20% of total solids (Saidu et al., 2016).

However, most of the AD technologies and relevant systems are mainly used on an industrial scale or are still in the laboratory development stage. Urgency is needed to design and develop a high-quality economical system which is efficient for urban households, resulting in a process that is widely accepted for processing household FW and reducing GHG emissions.

For two stage processes, the first stage involves hydrogen as a product (also called dark fermentation) but also includes alcohols and lactic acid. The optimal pH range and temperature in this stage are 5.5 and 55 °C, respectively (Micolucci, 2014). For the second stage, the main product is methane followed by ammonia and bicarbonate that increases the buffer capacity.

6.5 Conclusion

Research into FW as the sole feedstock for AD is in its infancy. Further research into the use of small-scale AD has to take into consideration the complex biochemical characteristics of food waste and the special survival and growth environment requirements of methanogens. This involves the strict control of the pH and temperature as well as other variables involved in AD. These variables include the need for growth cycles of more than 6 days for methane production and lower TSs. Finally, consideration must be given to AD pilot plant design for HFW treatment, including inoculation, pretreatment of feedstock and the multi-staging of AD technology systems for the purpose of accelerating digestion process and increasing methane production.

6.6 References

USEPA (USEPA) 2006, *Technology: Multi-Stage Anaerobic Digestion*, by (USEPA), USEPA.

Ahamed, A, Chen, CL, Rajagopal, R, Wu, D, Mao, Y, Ho, IJR, Lim, JW & Wang, JY 2015, 'Multi-phased anaerobic baffled reactor treating food waste', *Bioresource Technology*, vol. 182, pp. 239-44.

Ahern, EP, Deane, P, Persson, T, Ó Gallachó ir,B & Murphy, JD 2015, 'A perspective on the potential role of renewable gas in a smart energy island system', *Renewable Energy*, vol. 78, pp. 648-56.

Anderson, K, Sallis, P & Uyanik, S 2003, '24 - Anaerobic treatment processes', in *Handbook of Water and Wastewater Microbiology*, Academic Press, London, pp. 391-426, DOI http://dx.doi.org/10.1016/B978-012470100-7/50025-X, .

Ansari, AJ, Hai, FI, Guo, W, Ngo, HH, Price, WE & Nghiem, LD 2015, 'Selection of forward osmosis draw solutes for subsequent integration with anaerobic treatment to facilitate resource recovery from wastewater', *Bioresource Technology*, vol. 191, pp. 30-6.

Ariunbaatar, J 2014, 'Methods to enhance anaerobic digestion of food waste', PhD thesis, Université Paris-Est, via Star Lge Upec-upem, <https://tel.archives-ouvertes.fr/tel-01206170>.

Banksa, CJ, Chesshireb, M, Heavena, S & Arnoldb, R 2011, 'Anaerobic digestion of source segregated domestic food waste: performance assessment by mass and energy balance', *Bioresource Technology*, vol. 102, no. 2, p. 9.

Bashir, BH & Matin, A 2004, 'Combined effect of calcium and sodium on potassium toxicity in anaerobic treatment processes', *Electron. J. Environ. Agric. Food Chem*, vol. 4, pp. 670-6.

Bożym, M, Florczak, I, Zdanowska, P, Wojdalski, J & Klimkiewicz, M 2015, 'An analysis of metal concentrations in food wastes for biogas production', *Renewable Energy*, vol. 77, pp. 467-72.

Brown, D & Li, Y 2013, 'Solid state anaerobic co-digestion of yard waste and food waste for biogas production', *Bioresource Technology*, vol. 127, no. Supplement C, pp. 275-80.

Campanaro, S, Treu, L, Kougias, PG, De Francisci, D, Valle, G & Angelidaki, I 2016, 'Metagenomic analysis and functional characterization of the biogas microbiome using high throughput shotgun sequencing and a novel binning strategy', *Biotechnology for Biofuels*, vol. 2016, no. 9:26.

Carlsson, M, Lagerkvist, A & Morgan-Sagastume, F 2012, 'The effects of substrate pre-treatment on anaerobic digestion systems: A review', *Waste Management*, vol. 32, no. 9, pp. 1634-50.

Carrère, H, Dumas, C, Battimelli, A, Batstone, D, Delgenès, J, Steyer, J & Ferrer, I 2010, 'Pretreatment methods to improve sludge anaerobic degradability: a review', *Journal of Hazardous Materials*, vol. 183, no. 1, pp. 1-15.

Cesaro, A & Belgiorno, V 2013, 'Sonolysis and ozonation as pretreatment for anaerobic digestion of solid organic waste', *Ultrasonics Sonochemistry*, vol. 20, no. 3, pp. 931-6.

Chen, Y, Cheng, JJ & Creamer, KS 2008, 'Inhibition of anaerobic digestion process: A review', *Bioresource Technology*, vol. 99, no. 10, pp. 4044-64.

CHENG, L, ZHENG, Z-Z, WANG, C & ZHANG, H 2016, 'Recent advances in methanogens', *Microbiology China*, vol. 43, no. 5, p. 22.

Chu, C, Lee, D, Chang, B-V, You, C & Tay, J 2002, '"Weak" ultrasonic pre-treatment on anaerobic digestion of flocculated activated biosolids', *Water Research*, vol. 36, no. 11, pp. 2681-8.

Climent, M, Ferrer, I, Baeza, MdM, Artola, A, Vázquez, F & Font, X 2007, 'Effects of thermal and mechanical pretreatments of secondary sludge on biogas production under thermophilic conditions', *Chemical Engineering Journal*, vol. 133, no. 1–3, pp. 335-42.

Curry, N & Pillay, P 2012, 'Biogas prediction and design of a food waste to energy system for the urban environment', *Renewable Energy*, vol. 41, pp. 200-9.

—— 2015, 'Integrating solar energy into an urban small-scale anaerobic digester for improved performance', *Renewable Energy*, vol. 83, pp. 280-93.

De Clercq, D, Wen, Z, Gottfried, O, Schmidt, F & Fei, F 2017, 'A review of global strategies promoting the conversion of food waste to bioenergy via anaerobic digestion', *Renewable and Sustainable Energy Reviews*, vol. 79, no. 2017, p. 18.

Díaz, I, Pérez, C, Alfaro, N & Fdz-Polanco, F 2015, 'A feasibility study on the bioconversion of CO2 and H2 to biomethane by gas sparging through polymeric membranes', *Bioresource Technology*, vol. 185, pp. 246-53.

Duda, RM, da Silva Vantini, J, Martins, LS, de Mello Varani, A, Lemos, MVF, Ferro, MIT & de Oliveira, RA 2015, 'A balanced microbiota efficiently produces methane in a novel high-rate horizontal anaerobic reactor for the treatment of swine wastewater', *Bioresource Technology*, vol. 197, pp. 152-60.

Ecke, H & Lagerkvist, A 2000, *Anaerobic Treatment of Putrescible Refuse*, Lulea University of Technology.

El-Mashad, HM, Zeeman, G, van Loon, WKP, Bot, GPA & Lettinga, G 2004, 'Effect of temperature and temperature fluctuation on thermophilic anaerobic digestion of cattle manure', *Bioresource Technology*, vol. 95, no. 2, pp. 191-201.

Engelhart, M, Krüger, M, Kopp, J & Dichtl, N 2000, 'Effects of disintegration on anaerobic degradation of sewage excess sludge in downflow stationary fixed film digesters', *Water Science and Technology*, vol. 41, no. 3, pp. 171-9.

Esposito, G, Frunzo, L, Panico, A & Pirozzi, F 2011, 'Modelling the effect of the OLR and OFMSW particle size on the performances of an anaerobic co-digestion reactor', *Process Biochemistry*, vol. 46, no. 2, pp. 557-65.

Ferrer, I, Ponsá, S, Vázquez, F & Font, X 2008, 'Increasing biogas production by thermal (70 °C) sludge pre-treatment prior to thermophilic anaerobic digestion', *Biochemical Engineering Journal*, vol. 42, no. 2, pp. 186-92.

Fisgativa, H, Tremier, A & Dabert, P 2016, 'Characterizing the variability of food waste quality: A need for efficient valorisation through anaerobic digestion', *Waste Management*, vol. 50, pp. 264-74.

Flanders Health Blog 2017, *Alkalinity and pH*.

Gavala, HN, Yenal, U, Skiadas, IV, Westermann, P & Ahring, BK 2003, 'Mesophilic and thermophilic anaerobic digestion of primary and secondary sludge. Effect of pre-treatment at elevated temperature', *Water Research*, vol. 37, no. 19, pp. 4561-72.

Gouveia, J, Plaza, F, Garralon, G, Fdz-Polanco, F & Peña, M 2015, 'Long-term operation of a pilot scale anaerobic membrane bioreactor (AnMBR) for the treatment of municipal wastewater under psychrophilic conditions', *Bioresource Technology*, vol. 185, pp. 225-33.

Guo, X, Wang, C, Sun, F, Zhu, W & Wu, W 2014, 'A comparison of microbial characteristics between the thermophilic and mesophilic anaerobic digesters exposed to elevated food waste loadings', *Bioresource Technology*, vol. 152, pp. 420-8.

Guo, Y, Kong, X, Liu, w, Li, D, wang, D, Yuan, Z & Sun, Y 2011, 'Effects of organic loading rate on anaerobic digestion of food waste at room temperature', *Transactions of the Chinese Society of Agricultural Engineering*, vol. 27, no. 1, p. 5.

Hartmann, H & Ahring, BK 2006, 'Strategies for the anaerobic digestion of the organic fraction of municipal solid waste: an overview', *Water Science and Technology*, vol. 53, no. 8, pp. 7-22.

Heaven, S, Zhang, Y, Arnold, R, Paavola, T, Vaz, F & Cavinato, C 2010, *Compositional analysis of food waste from study sites in geographically distinct regions of Europe*, D2.1, Seventh cooperation.

Hendriks, ATWM & Zeeman, G 2009, 'Pretreatments to enhance the digestibility of lignocellulosic biomass', *Bioresource Technology*, vol. 100, no. 1, pp. 10-8.

Hu, Y, Pang, Y, Yuan, H, Zou, D, Liu, Y, Zhu, B, Chufo, WA, Jaffar, M & Li, X 2015, 'Promoting anaerobic biogasification of corn stover through biological pretreatment by liquid fraction of digestate (LFD)', *Bioresource Technology*, vol. 175, pp. 167-73.

Izumi, K, Okishio, Y-k, Nagao, N, Niwa, C, Yamamoto, S & Toda, T 2010, 'Effects of particle size on anaerobic digestion of food waste', *International Biodeterioration & Biodegradation*, vol. 64, no. 7, pp. 601-8.

Jilin University, C 2017, *第八章 厌氧活性污泥法生物处理废水*, <(http://cc.jlu.edu.cn/G2S/Template/View.aspx?courseId=40&topMenuId=117822&action=view&type=1&name=&menuType=1&curfolid=117870)>.

Kianmehr, P, Parker, W & Seto, P 2010, 'An evaluation of protocols for characterization of ozone impacts on WAS properties and digestibility', *Bioresource Technology*, vol. 101, no. 22, pp. 8565-72.

Kim, I, Kim, D & Hyun, S 2000, 'Effect of particle size and sodium ion concentration on anaerobic thermophilic food waste digestion', *Water Science and Technology*, vol. 41, no. 3, pp. 67-73.

Kim, M-S, Kim, D-H & Yun, Y-M 2017, 'Effect of operation temperature on anaerobic digestion of food waste: Performance and microbial analysis', *Fuel*, vol. 209, no. 2017, p. 8.

Koch, K, Bajón Fernández, Y & Drewes, JE 2015, 'Influence of headspace flushing on methane production in Biochemical Methane Potential (BMP) tests', *Bioresource Technology*, vol. 186, pp. 173-8.

Kosovska, H 2006, 'THE BIOLOGICAL TREATMENT OF ORGANIC FOOD WASTE', Master thesis, Royal Institute of Technology.

Kugelman, IJ & McCarty, PL 1965, 'Cation Toxicity and Stimulation in Anaerobic Waste Treatment', *Journal (Water Pollution Control Federation)*, vol. 37, no. 1, pp. 97-116.

Lee, J, Hwang, B, Koo, T, Shin, S, Kim, W & Hwang, S 2014, 'Temporal variation in methanogen communities of four different full-scale anaerobic digesters treating food waste-recycling wastewater', *Bioresour Technol*, vol. 168, p. 4.

Leung, DYC & Wang, J 2016, 'An overview on biogas generation from anaerobic digestion of food waste', *International Journal of Green Energy*, vol. 13, no. 2, pp. 119-31.

Li, L, Feng, L, Zhang, R, He, Y, Wang, W, Chen, C & Liu, G 2015, 'Anaerobic digestion performance of vinegar residue in continuously stirred tank reactor', *Bioresource Technology*, vol. 186, pp. 338-42.

Li, L, He, Q, Ma, Y, Wang, X & Peng, X 2015, 'Dynamics of microbial community in a mesophilic anaerobic digester treating food waste: Relationship between community structure and process stability', *Bioresource Technology*, vol. 189, pp. 113-20.

Li, Q, Li, Y-Y, Qiao, W, Wang, X & Takayanagi, K 2015, 'Sulfate addition as an effective method to improve methane fermentation performance and propionate degradation in thermophilic anaerobic co-digestion of coffee grounds, milk and waste activated sludge with AnMBR', *Bioresource Technology*, vol. 185, pp. 308-15.

Lin, J, Zuo, J, Ji, R, Chen, X, Liu, F, Wang, K & Yang, Y 2012, 'Methanogenic community dynamics in anaerobic co-digestion of fruit and vegetable waste and food waste', *Journal of Environmental Sciences*, vol. 24, no. 7, pp. 1288-94.

Manser, ND, Mihelcic, JR & Ergas, SJ 2015, 'Semi-continuous mesophilic anaerobic digester performance under variations in solids retention time and feeding frequency', *Bioresource Technology*, vol. 190, pp. 359-66.

Manyi-Loh, CE, Mamphweli, SN, Meyer , EL, Okoh, AI, Makaka, G & Simon, M 2013, 'Microbial Anaerobic Digestion (Bio-Digesters) as an Approach to the Decontamination of Animal Wastes in Pollution Control and the Generation of Renewable Energy', *International journal of environmental research and public health*, vol. 2013, no. 10, p. 28.

Markou, G 2015, 'Improved anaerobic digestion performance and biogas production from poultry litter after lowering its nitrogen content', *Bioresource Technology*, vol. 196, pp. 726-30.

Martin-Ryals, A, Schideman, L, Li, P, Wilkinson, H & Wagner, R 2015, 'Improving anaerobic digestion of a cellulosic waste via routine bioaugmentation with cellulolytic microorganisms', *Bioresource Technology*, vol. 189, pp. 62-70.

Micolucci, FG, M.; Bolzonella, D.; Pavan, P. 2014, 'Automatic process control for stable bio-hythane production in two-phase thermophilic anaerobic digestion of food waste', *International Journal of Hydrogen Energy*, vol. 39, no. 31, pp. 17563-72.

Micolucci, FG, M.; Malamis, D.; Bolzonella, D.; Pavan, P.; Cecchi, F. 2015, 'Analysis of Meso/Thermo AD Process Applied to Pressed Biowaste', *Waste and Biomass Valorization*, vol. 6, no. 5, pp. 723-31.

Montingelli, ME, Tedesco, S & Olabi, AG 2015, 'Biogas production from algal biomass: A review', *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 961-72.

Nallathambi Gunaseelan, V 1997, 'Anaerobic digestion of biomass for methane production: A review', *Biomass and Bioenergy*, vol. 13, no. 1–2, pp. 83-114.

Papa, G, Rodriguez, S, George, A, Schievano, A, Orzi, V, Sale, KL, Singh, S, Adani, F & Simmons, BA 2015, 'Comparison of different pretreatments for the production of bioethanol and biomethane from corn stover and switchgrass', *Bioresource Technology*, vol. 183, pp. 101-10.

Parawira, W, Murto, M, Read, JS & Mattiasson, B 2005, 'Profile of hydrolases and biogas production during two-stage mesophilic anaerobic digestion of solid potato waste', *Process Biochemistry*, vol. 40, no. 9, pp. 2945-52.

Patil, JH, Raj, MA & Gavimath, CC 2011, 'Study on effect of pretreatment methods on biomethanation of water hyacinth', *International Journal of Advanced Biotechnology and Research*, vol. 2, no. 1, p. 5.

Pokój, T, Bułkowska, K, Gusiatin, ZM, Klimiuk, E & Jankowski, KJ 2015, 'Semi-continuous anaerobic digestion of different silage crops: VFAs formation, methane yield from fiber and non-fiber components and digestate composition', *Bioresource Technology*, vol. 190, pp. 201-10.

Rafique, R, Poulsen, TG, Nizami, A-S, Asam, Z-u-Z, Murphy, JD & Kiely, G 2010, 'Effect of thermal, chemical and thermo-chemical pre-treatments to enhance methane production', *Energy*, vol. 35, no. 12, pp. 4556-61.

Reilly, M, Dinsdale, R & Guwy, A 2015, 'Enhanced biomethane potential from wheat straw by low temperature alkaline calcium hydroxide pre-treatment', *Bioresource Technology*, vol. 189, pp. 258-65.

Romano, RT & Zhang, R 2008, 'Co-digestion of onion juice and wastewater sludge using an anaerobic mixed biofilm reactor', *Bioresource Technology*, vol. 99, no. 3, pp. 631-7.

Saidu, I, Aminu, SU, Aliyu, Y & Garba, B 2016, 'Current Developments in Anaerobic Digestion of Food Waste Coupled with Combined Heat and Power Generation of Electricity', in *International Proceedings of Chemical, Biological and Environmental Engineering*, vol. IPCBEE (2016).

Schmidt, JE & Ahring, BK 1993, 'Effects of magnesium on thermophilic acetate-degrading granules in upflow anaerobic sludge blanket (UASB) reactors', *Enzyme and microbial technology*, vol. 15, no. 4, pp. 304-10.

Serna-Maza, A, Heaven, S & Banks, CJ 2015, 'Biogas stripping of ammonia from fresh digestate from a food waste digester', *Bioresource Technology*, vol. 190, pp. 66-75.

Sitorus, B, Sukandar & Panjaitan, SD 2013, 'Biogas Recovery from Anaerobic Digestion Process of Mixed Fruit -Vegetable Wastes', *Energy Procedia*, vol. 32, pp. 176-82.

Soto, M, Méndez, R & Lema, JM 1993, 'Sodium inhibition and sulphate reduction in the anaerobic treatment of mussel processing wastewaters', *Journal of Chemical Technology & Biotechnology*, vol. 58, no. 1, pp. 1-7.

Sumardiono, S, Syaichurrozi, I, Budiyono & Sasongko, SB 2013, 'The Effect of COD/N Ratios and pH Control to Biogas Production from Vinasse', *International Journal of Biochemistry Research & Review*, vol. 3, no. 4, p. 13.

Sundberg, C 2005, 'Improving Compost Process Efficiency by Controlling Aeration, Temperature and pH', Swedish University of Agricultural Sciences.

Tampio, E, Ervasti, S, Paavola, T, Heaven, S, Banks, C & Rintala, J 2014, 'Anaerobic digestion of autoclaved and untreated food waste', *Waste Manag*, vol. 34, no. 2, pp. 370-7.

Vanwonterghem, I, Jensen, PD, Rabaey, K & Tyson, GW 2015, 'Temperature and solids retention time control microbial population dynamics and volatile fatty acid production in replicated anaerobic digesters', *Scientific Reports*, vol. 5, p. 8496.

Wang, B, Liu, J, Han, Z, Liu, J & Hu, B 2014, 'Recent Progress and Classification of Methanogens', *Genomics and Applied Biology*, vol. 33, no. 2, p. 8.

Wang, L 2011, 'Different Pretreatments to Enhance Biogas Production-A comparison of thermal, chemical and ultrasonic methods', Master thesis, Halmstad University.

Wang, P, Wang, H, Qiu, Y, Ren, L & Jiang, B 2018, 'Microbial characteristics in anaerobic digestion process of food waste for methane production–A review', *Bioresource Technology*, vol. 248, no. 2018, p. 8.

WU, M, ZHANG, R, ZHOU, J, XIE, X, YONG, X, YAN, Z, GE, M & ZHENG, T 2014, 'Effect of temperature on methanogens metabolic pathway and structures of predominant bacteria', *CIESC Journal*, vol. 65, no. 5, p. 5.

Xu, F, Li, Y, Ge, X, Yang, L & Li, Y 2018, 'Anaerobic digestion of food waste – Challenges and opportunities', *Bioresource Technology*, vol. 247, pp. 1047-58.

Zhang, B, Zhang, LL, Zhang, SC, Shi, HZ & Cai, WM 2005, 'The Influence of pH on Hydrolysis and Acidogenesis of Kitchen Wastes in Two-phase Anaerobic Digestion', *Environmental technology*, vol. 26, no. 3, pp. 329-40.

Zhang, C, Su, H, Baeyens, J & Tan, T 2014, 'Reviewing the anaerobic digestion of food waste for biogas production', *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 383-92.

Zhang, G, Li, C, Ma, D, Zhang, Z & Xu, G 2015, 'Anaerobic digestion of antibiotic residue in combination with hydrothermal pretreatment for biogas', *Bioresource Technology*, vol. 192, pp. 257-65.

Zhang, J, Li, W, Lee, J, Loh, K-C, Dai, Y & Tong, YW 2017, 'Enhancement of biogas production in anaerobic co-digestion of food waste and waste activated sludge by biological co-pretreatment', *Energy*, no. 2017, p. 8.

Zhang, Q, Hu, J & Lee, D-J 2016, 'Biogas from anaerobic digestion processes: Research updates', *Renewable Energy*.

Zhang, R, El-Mashad, HM, Hartman, K, Wang, F, Liu, G, Choate, C & Gamble, P 2007, 'Characterization of food waste as feedstock for anaerobic digestion', *Bioresource Technology*, vol. 98, no. 4, pp. 929-35.

Zhong, Y, Ruan, Z, Zhong, Y, Archer, S, Liu, Y & Liao, W 2015, 'A self-sustaining advanced lignocellulosic biofuel production by integration of anaerobic digestion and aerobic fungal fermentation', *Bioresource Technology*, vol. 179, pp. 173-9.

小丽， 2011, *常用缓冲溶液的配制方法* 2019, <https://wenku.baidu.com/view/>.

Chapter 7: Household food waste anaerobic digestion (AD) pilot plant - design and construction

7.1 Preamble

"Small-scale" AD reactor facilities for household organic waste exist mainly in rural areas (Curry and Pillay, 2012). However, these tend to be technologically unsophisticated and the resulting longer digestion/reacting times (normally at least 40 days) require a larger reactor unit size. This precludes their use within the dwellings themselves.

With recent advances in waste treatment technologies (Ariunbaatar, 2014), AD is attracting a high level of research interest from waste management industries. These studies indicate that there are many variables within the AD process, such as reaction time and methane production rate that need to be optimized. This is especially true with respect to small-scale anaerobic digesters where there are still many specific challenges.

Zhang et al. (2016) have searched up to 20,000 scientific papers in the Web of Scienceth database for general research on AD. On the basis of their work it is estimated that there are 128,462 citations from 500 papers. Given such a huge volume of work, this project has focused on the more specific use of AD in HFW management.

The composition of HFW includes vegetable waste, peelings and trimmings, fruit skins, spoilt fruit, cooked and uncooled meat, bones, fats, egg-shells, used teabags, coffee grounds, rice, bread and pastries, cooked FW, etc. FW normally contains 80-97% volatile solids (VS) (Curry and Pillay, 2012), 70-90% water and a carbon to nitrogen ratio (C/N) of 14.7–36.4 (Zhang et al., 2014). Such characteristics make it a perfect substrate for AD. Currently, FW disposal into landfill has been banned in most countries. There are also drawbacks with respect to other disposal methods for FW due to the problem of too high a moisture content (MC) and air pollution arising from incineration or gasification (see Chapter 2). Furthermore, given the possibility of disease arising from FW, AD treatment has become the management method of choice since it is environmentally friendly and has potential economic benefits for the FW industry.

The biogas generated from FW through anaerobic digestion includes four main stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis, depicted in Figure 7.1 (same as Figure 2.4).

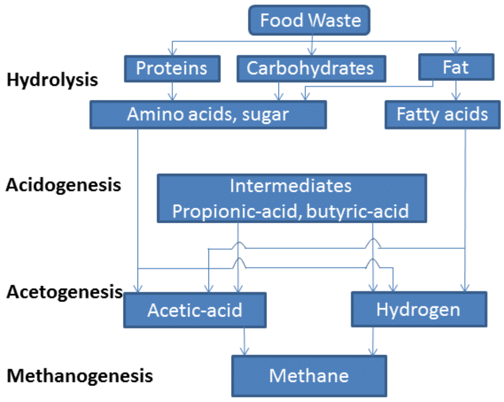


Figure7.1 Organic waste anaerobic digestion process (Tsang, 2013)

During these 4 stages, the composition of the feedstock, the pH, temperature, nutrient level, C:N ratio and operation method all contribute to the final production of the biogas methane (Tampio et al., 2014, Zhang et al., 2014). For each of these stages, different methodologies are employed to optimize the digestion process. A highly efficient AD system is required to obtain optimum production of methane and other combustible gases.

On the basis of the examination of the available literature on HFW/AD (Chapter 2) and taking into account the results of the extensive survey of HFW management across different accommodation types in Melbourne (Chapters 4 & 5), we have designed, developed and trialled a novel system for the AD of HFW with a view to incorporating it into a domestic setting. The pilot plant thus constructed has been assembled using readily available parts with the aim of minimizing costs.

7.2 Pilot plant design and construction

7.2.1 Design principles

As described in Section 6.2.1, the purpose of the pilot plant was to optimize the hydrolysis of FW in order to maximize the production of biogas. However, due to certain constraints some variables had limitations. For example, the temperature could not exceed 70 ° C.In addition, the choice of an inoculate derived from animal manure was considered not to be suitable for the AD of HFW. Moreover, the industrial system could not be simply copied and miniaturized as it involves complex and costly high technology that is outside the scope and intent of this pilot plant concept. The design of the pilot plant also took into account the guidelines of Engineers Australia (Australia, 2010) to reflect public concerns and to highlight economic and safety aspects.

The overall design of the pilot plant is depicted in Figure 7.2. More detailed components and attachments are shown in Figures 7.3 and 7.4. The designations of the numerals 1 to 17 in Figure 7.2 are provided in Tables 7.1 and 7.2. The overall rationale for the design is as follows:

The system has been designed so as to allow various processes to be independently investigated. Thus, in Figure 7.2, the mass digestion system consists of the three biomass Tanks 1, 2 and 3 and the Transfer Vessel 4. Tank 1 was designed to study biomass hydrolysis, Tank 2 was designed to allow the study of acidogenesis and acetogenesis and Tank 3 was designed to allow the study of methanogenesis. The Transfer Vessel 4 was used to study mass transfer. The stirring and heating in the first anaerobic digestion tank, Tank 2, was controlled in order to accelerate fermentation and to reduce inhibitory conditions - with the aim of increasing the gas yield and production rate. The last digestion tank, Tank 3, was also used to recycle the liquid residual into the first tank as an additional inoculate and to increase the pH of the feedstock. The electrical system was comprised of one 240 AC – 12DVC power supply, five small circle pumps, two temperature monitor relays, one timing stirrer and one floating controller. A 12 DVC power supply was ideal for reducing the energy input and to minimize risk during the experiments. The heating system consisted of one urn and two heat exchange coils, see Tables 7.1 & 7.2 and Figure 7.4. According to Ventura et al. (2014), mesophilic acidogenesis and thermophilic methanogenesis are best for the operation of multi reactor FW/AD, in terms of an ideal microbial community and optimal CH_4 production. This is favoured by an ambient temperature in Tank 1 and higher temperatures in Tanks 2 and 3, where heating systems have been installed. The importance of temperature monitoring and control has also been emphasised by Kythreotou (2014). The biogas collection system, Figure 7.3, was designed for the storage and measurement of gas from Tanks 2 and 3 and from the Transfer Vessel 4.

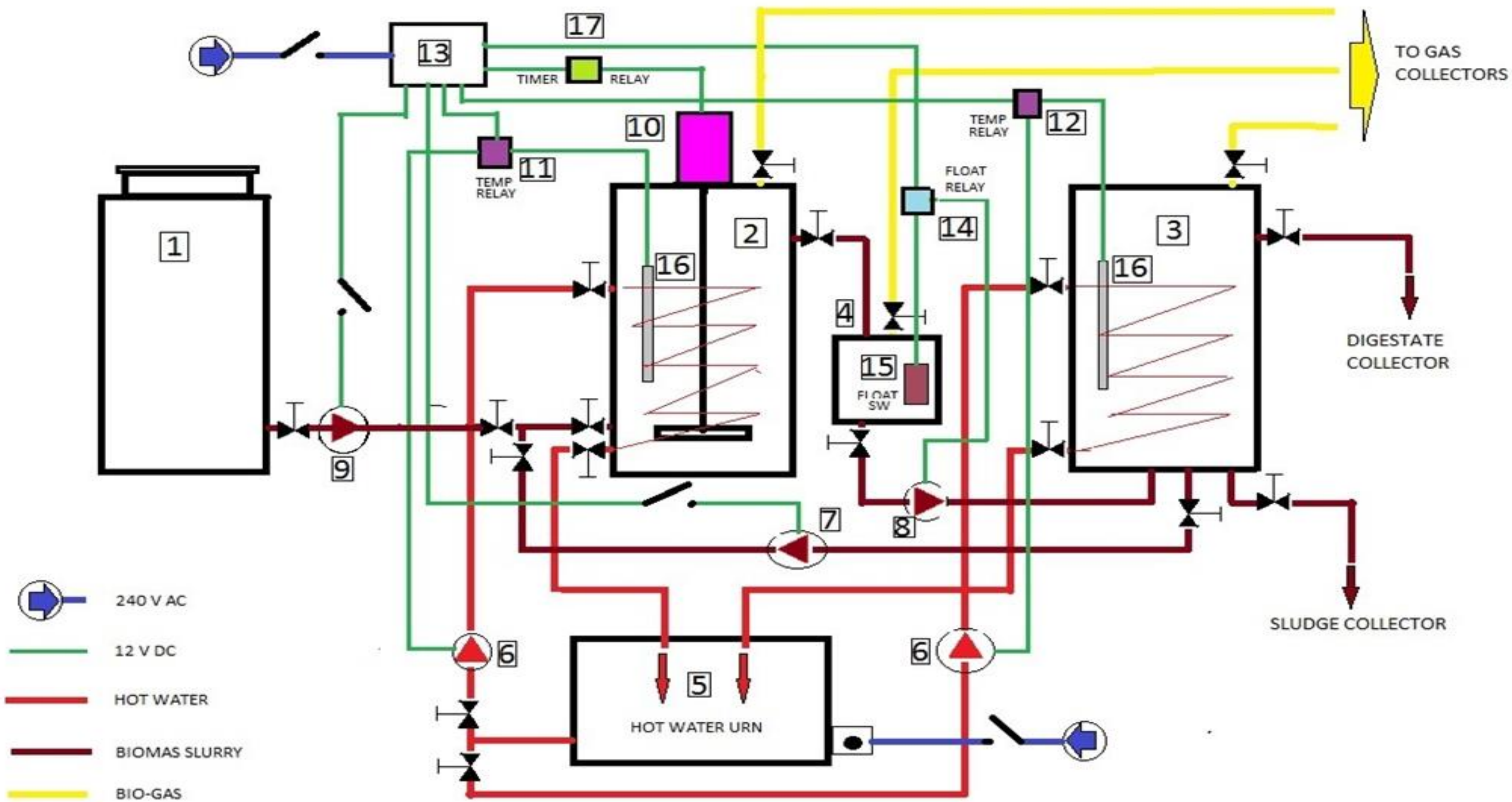


Figure7.2 A schematic of the HFW/AD pilot plant. The designations of the numerals 1 to 17 are provided in Table 7.1 (and 7.2). This schematic should be interpreted with reference to Table 7.1

Table 7.1 The description of items numbered from 1 to 17 as shown in Figure 7.2

Item number	Description
1	Biomass storage and Aerobic digestion tank
2, 3	Anaerobic digestion tank
4	Digestate transfer vessel
5	Hot water Urn
6	Hot water pump
7	Liquor circulation pump
8	Digestate transfer pump
9	Biomass supply pump
10	Stirrer
11, 12	Temperature relay
13	240 AC – 12DVC power supply
14	Float switch relay
15	Float switch
16	K – type thermocouple
17	Timer Stirrer

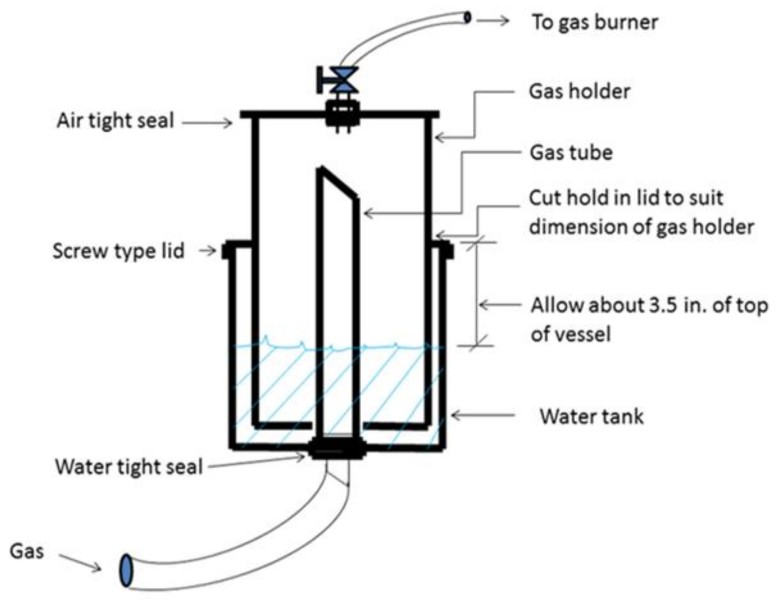


Figure7.3 The gas collector

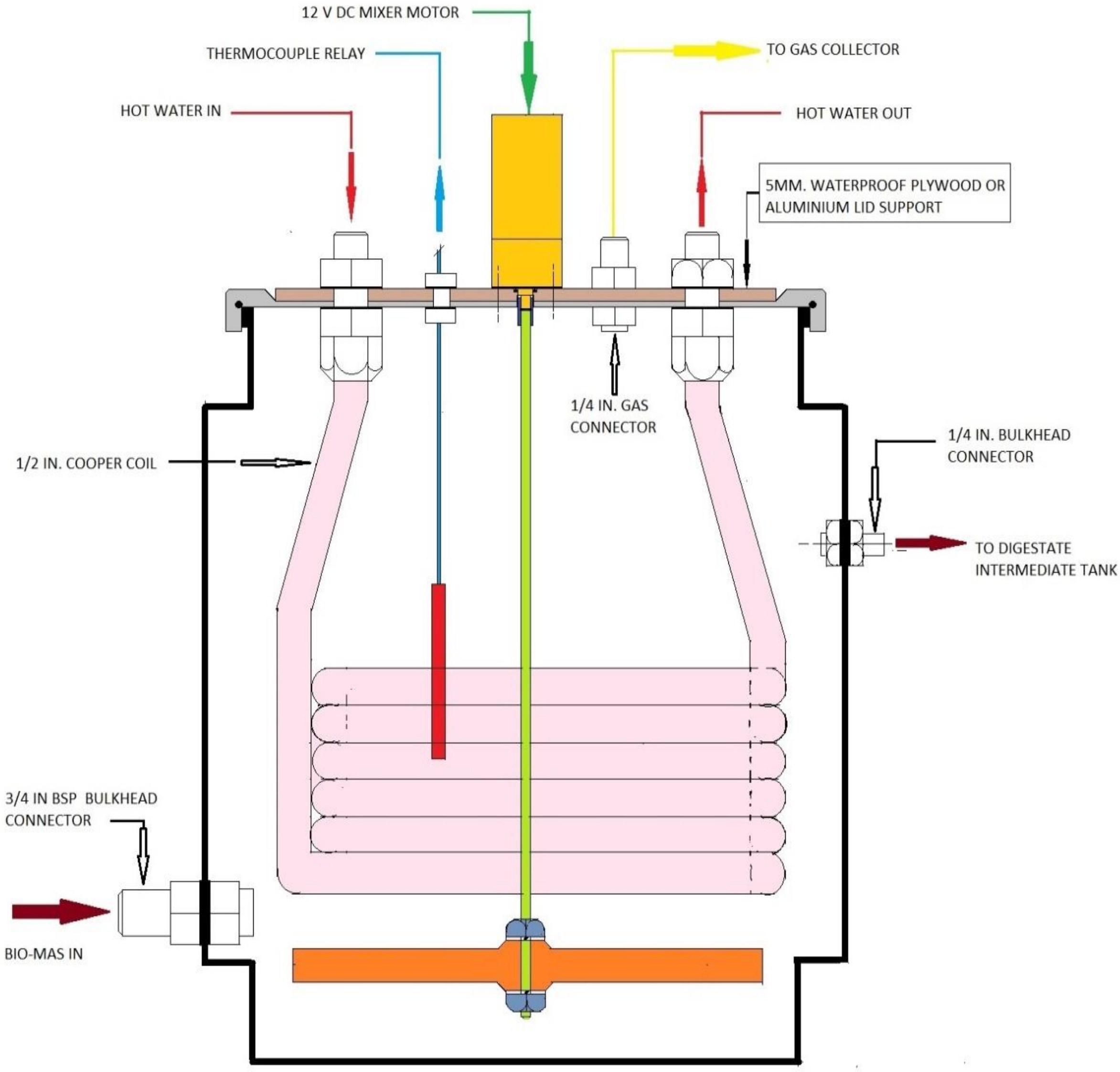


Figure7.4 Details of the inside of digestion Tank 2

7.2.2 Pilot plant construction

7.2.2.1 Materials

To avoid copper corrosion by acid, all parts inside the digestion tanks are made from plastic or stainless steel. Details of the components used in the construction are given in Table 7.2.

Table 7.2 Specification and supply details of the components used in the pilot plant construction

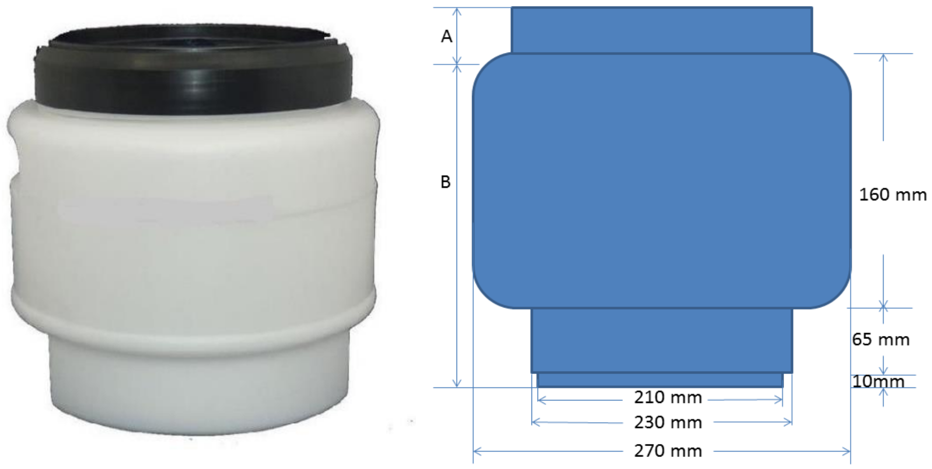
Item number, see Table 7.1 and Figure 7.2	Description	Detail / model	Manufacture / supplier	Quantity
1, 2, 3	Digestion tank	15 litre screw top drum	The Plastic Man	3
4	transfer vessel	3 litre air seal containers	The Plastic Man	1
5	Hot water Urn	APURD GL 347-A 20 litre stainless steel water boiler, 2.2 KW	Nisbet Express Catering Equipment	1
6 (right) and 9	Hot water and biomass pump	TOPSFLO TS5 12 VDC	Morassi & Williams	2
6(left) and 7, 8,	Hot water and Biomass pump	PROPUMPs, 12 VDC, 4 L/min Model: FL - 2202A	EDISONS	3
10	Stirrer motor	12 VDC Gear motor, 36 Rpm, 12 kg. cm. Model: YG2734	JAYCAR	1
11, 12	Temperature relay	12 VDC , NOVOUS, P/N 8032204024 N322	Ocean Controls	2
13	240 VAC – 12VDC power supply		Ocean Controls	1
14	Float switch relay	RLY- 006	Ocean Controls	1
15	Float switch	HES -108	Ocean Controls	1
16	K – type thermocouple	CMS-011	Ocean Controls	
17	Timer	12 VDC Timer programmable interval	Ocean Controls	1
18, 19	BSP valves		Ocean Controls	6
20	Tubing	5, 10, and 13 mm PVC	Bunning	
21	Heating coil	8 mm soft annealed copper pipe	Bunning	
22	Plastic fitting and tap		Bunning	
23	Blender		Bunning	1

7.2.2.2 Construction

The construction work is divided into four parts: **(i)** Digestion system; **(ii)** Heating system; (iii) Electrical system; (iv) Gas collection system – as follows:

(i) Digestion system

Reviews of both the literature and the HFW audit reports of three cities council have revealed that the average daily FW generation varies from 0.5 to 1.3 kg per household. For on-site domestic treatment, the size of the system must be kept small enough to ensure that it can be satisfactorily installed - for example, under a household kitchen bench. In addition, the system must be efficient, economic and easy to operate and maintain. Ideally, the size of each of the three digestion tanks should be as small as possible, preferably between 8 and 10 L. For this project, due to supply issues, slightly larger anaerobic tanks of 15 L had to be employed (The Plastic Man). These tanks are made from polyvinyl chloride (PVC) and can each withstand a pressure of up to 3 Bar (Figure 7.5). The volume of tank consists of two parts - A and B as indicated in Figure 7.5. The volume of part B (V_B) was set at 15 L as marked on the wall of each tank. Due to special shape of lid and mouth of the tanks, the volume of part A (V_A) is measured by using water to fully fill the tank and closed the lid. The tank was then opened and the volume of remaining water minus V_B is the V_A. The content volume of the tank was 1.9 L (V_A+V_B).



(a) (b)

Figure7.5 The 15 L digestion tank as supplied by The Plastic Man.

The detailed fitting of the three bio-vessels that are incorporated into the pilot plant is shown in Figures 7.6 to 7.8.

Tank 1 was designed to ferment the FW organic mass that is transformed during the change from aerobic to anaerobic conditions. During the fermentation of the organic FW, oxygen will be depleted at the bottom of **Tank 1**. Thus the contents of **Tank 1** are transferred into **Tank 2** through the bottom outlet (Figure 7.6). Acidogenesis and acetogenesis of the biomass mainly occurs in **Tank 2**. To speed up the digestion process a heating coil and auto stirrer have been placed inside the tank (Figures 7.7 and 7.4). The final stage of the methanogenesis (anaerobic) process takes place in **Tank 3**. Residue outputs and the final biomass input point and the biomass recycle point are shown in Figure 7.8. The bottom outlet is to allow for the collection of the residue precipitate while the upper enables the determination of the liquid/water outflow and the side link is used to recycle the liquid inoculate back to **Tank 2**, Figure 7.2.

In addition to **Tanks 1 to 3**, a **Transfer Vessel** (Sistemaplastics), Figure 7.9, was placed between **Tanks 2 and 3**, see Figure 7.2. A level float is installed inside the tank to control the digestate transfer pump (Number 8 in Figure 7.2). The outlet and inlet positions were installed so that samples could also be collected.

Because the temperature of the fermented material mass could rise to 60 ºC, the transfer tubes were chosen to accommodate temperatures as high as 100 ºC. Sampling outputs were installed as required.

The complete system is depicted in Figure 7.10.

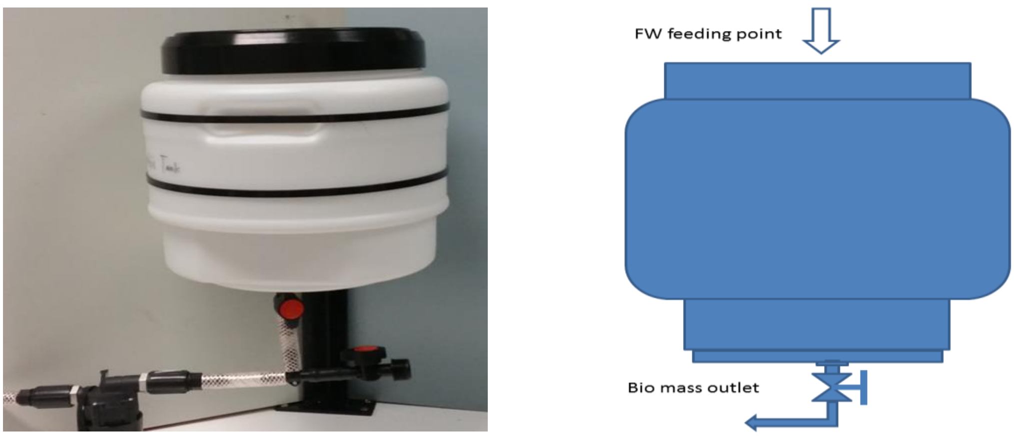


Figure7. 6 Fittings for Tank 1 (aerobic tank). See Figure 7.2

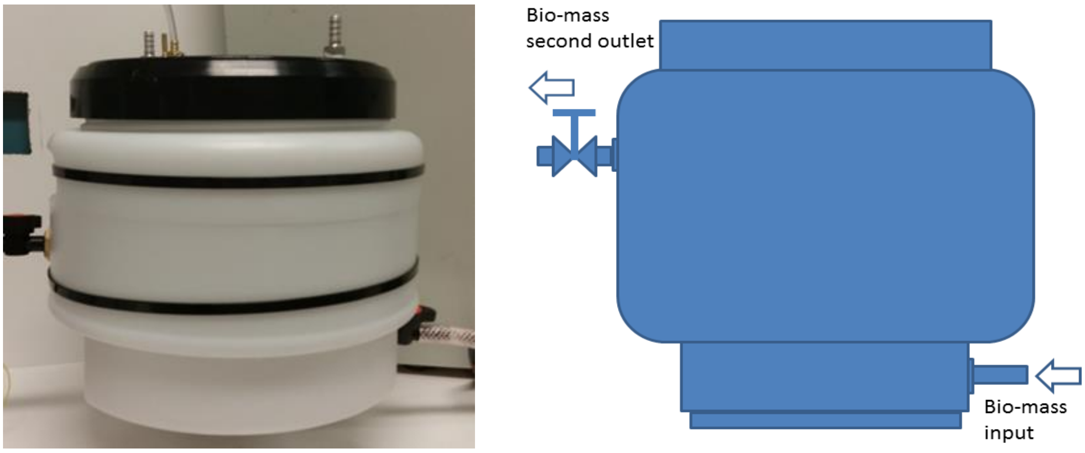


Figure7.7 Fittings for Tank 2 (anaerobic tank). See Figures 7.2 and 7.4

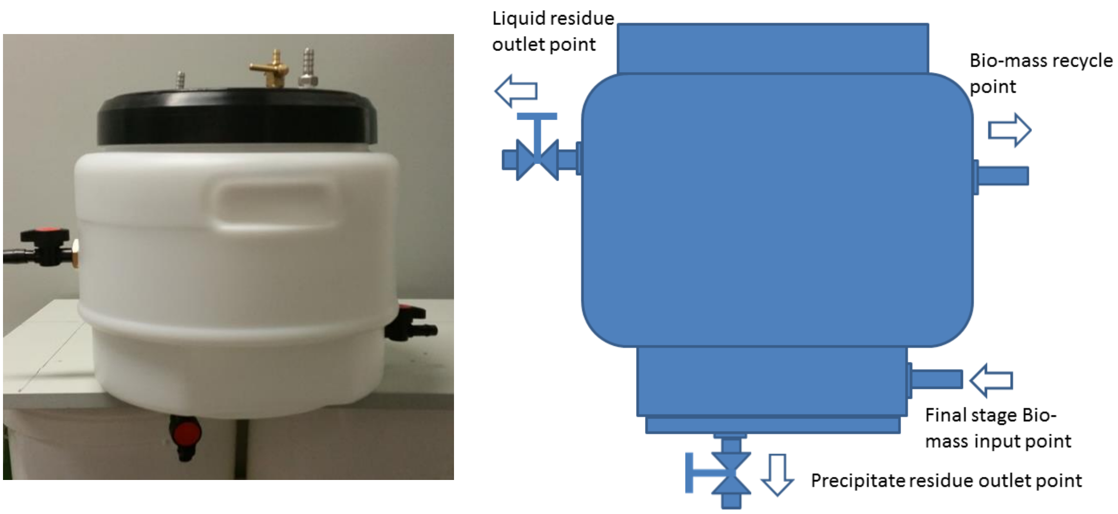


Figure7.8 Fittings for Tank 3 (anaerobic tank). See Figure 7.2

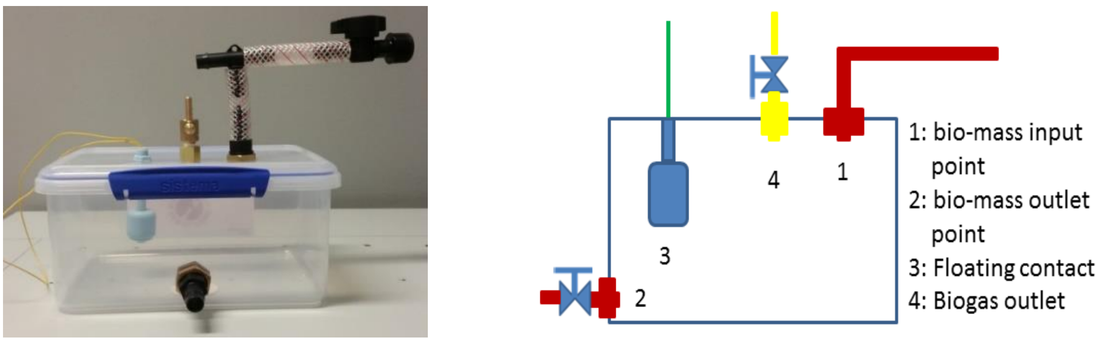


Figure7.9 Transfer Vessel placed between Tanks 2 and 3

Note that, having **Tank 1** higher than the inlet point of **Tank 2** then the liquid biomass can flow under gravity to Tank 2. With this arrangement, after three days of hydrolysis and degradation in **Tank 1,** the biomass at the bottom can be transferred to **Tank 2** without consuming additional energy.

The **Transfer Vessel** between **Tank 2 and 3** is also designed for settling down the foam that may form during acidogenesis and acetogenesis in **Tank 2**. Also the level of **Tank 2** relative to **Tank 3** to allow gravity to facilitate the mass flow. Figure 7.10 shows the whole system setting.

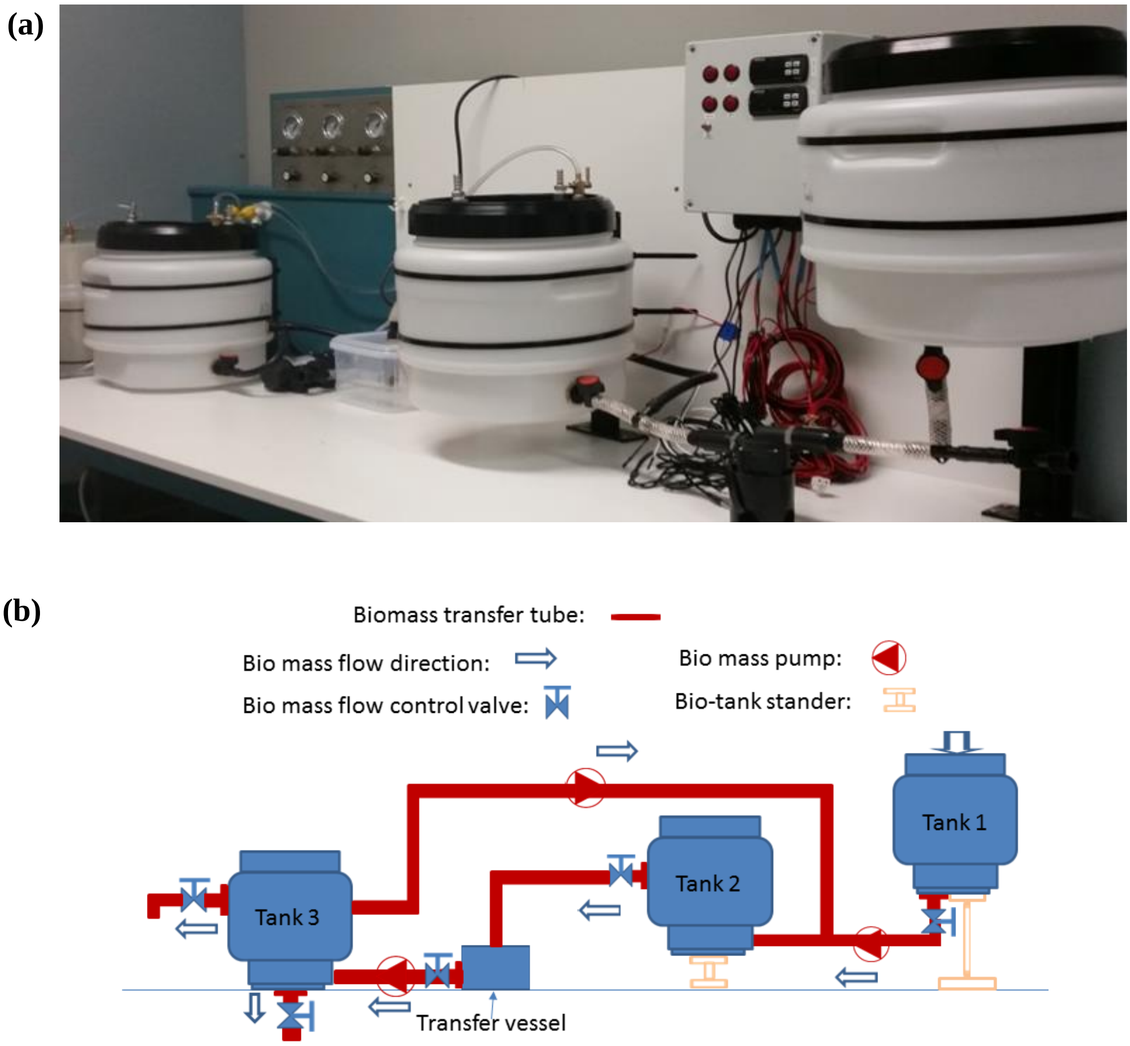
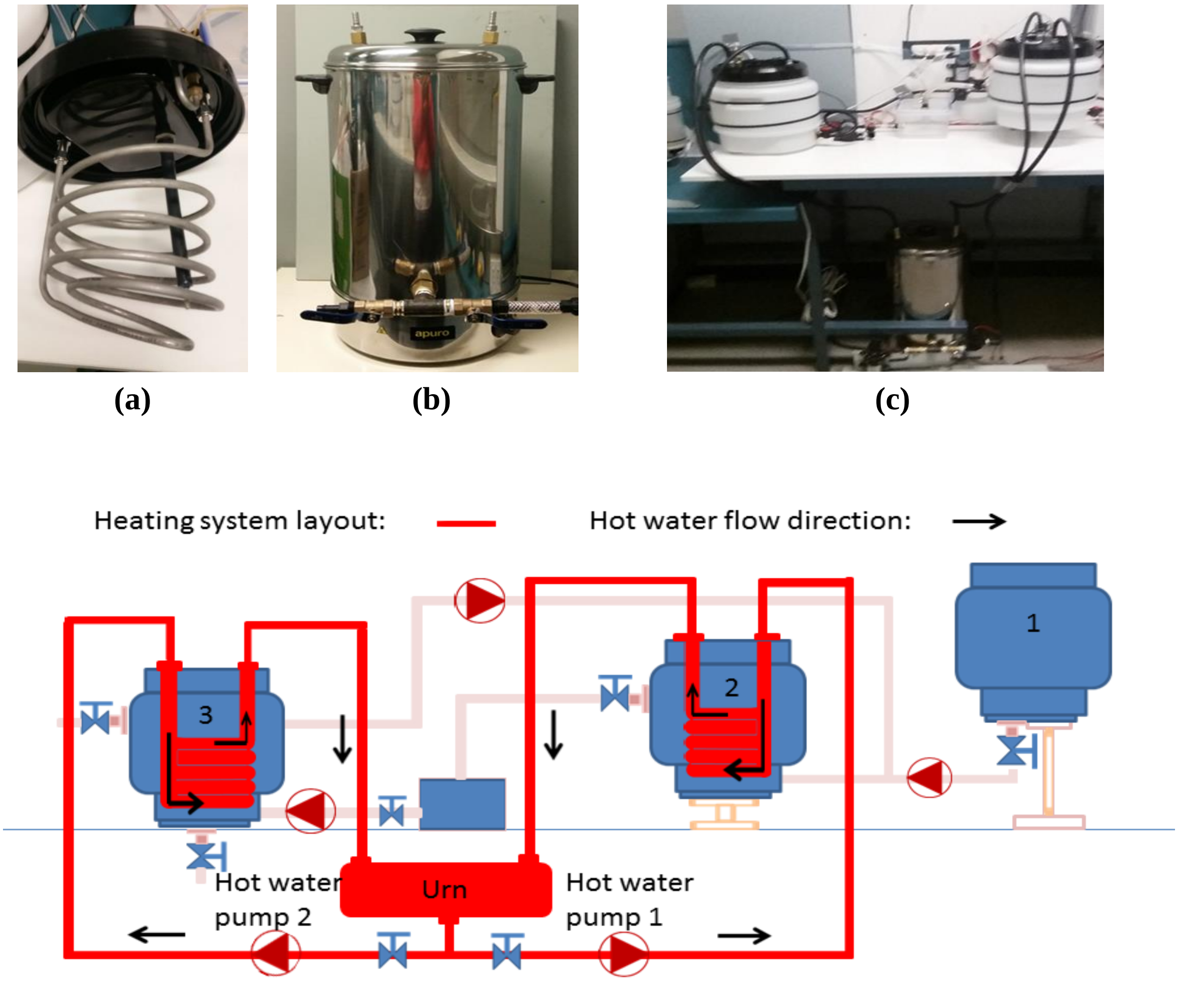


Figure7.10 (a) Photo of the final set-up **(b)** Schematic of final set-up shown in **(a)**

(ii) Heating system

The heating system is depicted in Figure 7.11. This includes two heating coils, Figure 7.11 (a), that are each installed in **Tanks 2 and 3**, an automatic electricity hot water urn, Figure 7.11 (b) and four heat resistant connecting tubes, Figure 7.11 (c) and (d). The heating coil was made from stainless steel to avoid possible corrosion from the acidogenesis and acetogenesis processes. The hot water inflow and outflow was from the lower side to the higher side to optimize the heat exchange efficiency between the heating coils and the biomass.

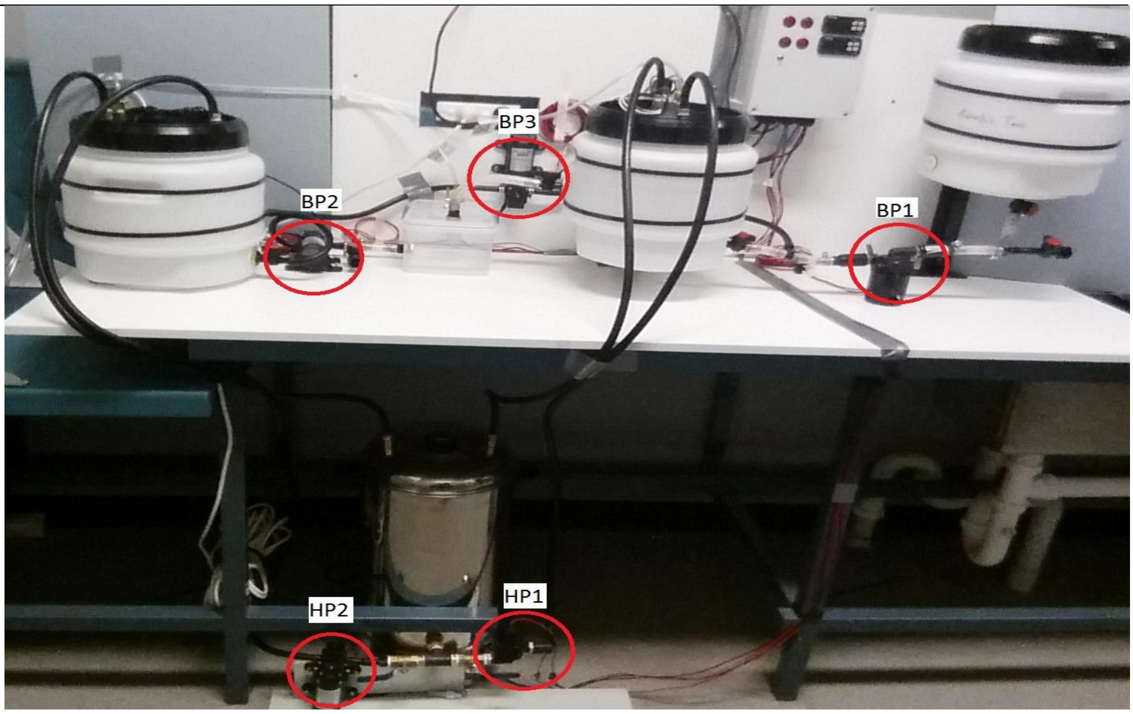


(d)

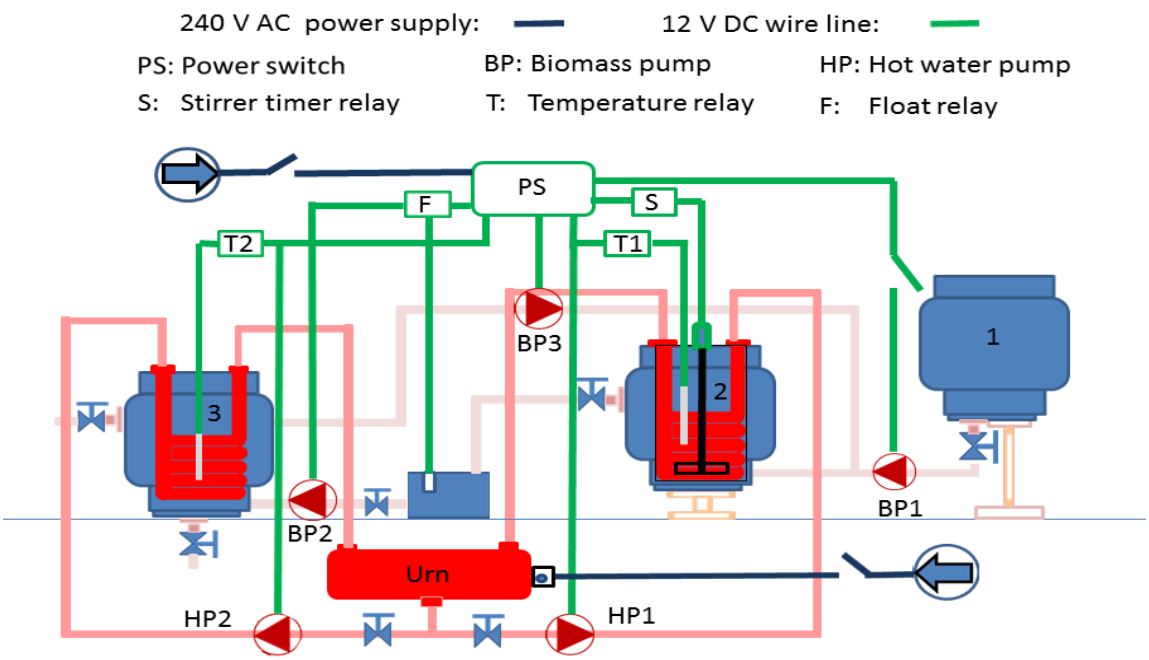
Figure7.11 Heating system details; **(a)** Heating coil; **(b)** Urn; **(c)** Connecting tubes; **(d)** Schematic

(iii) Electrical system

For safety and energy savings all the electrical equipment utilized a 12D CV power supply. The system layout is shown in Figure 7.12.



(a)

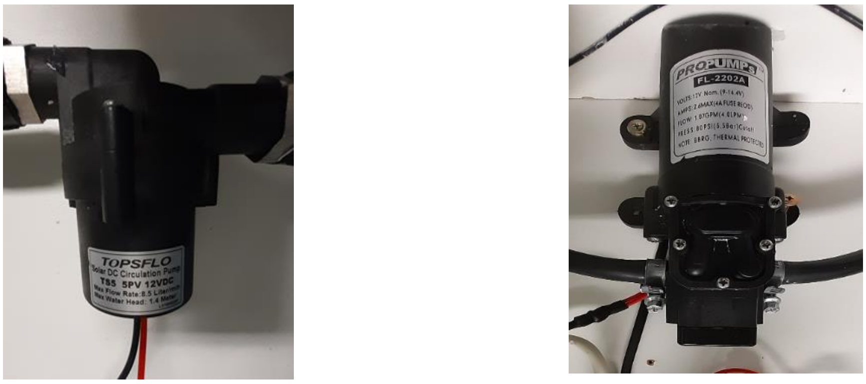


(b)

Figure7.12 **(a)** Photograph of the pilot plant set-up - pumps are circled in red. **(b)** Electrical layout

Five 12 DCV electric pumps were used for the pilot plant, Figure 7.2, Tables 7.1 and 7.2. Three were installed in the biomass system and two were installed in the heating system.

Bio Pump 1 (BP1) and Hot Water Pump 1 (HP1) were TOPSFLO Solar DC Circulation Pumps, Photo 7.1 (a). These were designed to ensure that the system can withstand temperatures of up to 110 °C, 10 Bar in pressure and a maximum flow of up to 8.5 L/min. Bio Pump 2 (BP2), Bio Pump 3 (BP3) and Hot Water Pump 2 (HP2) were supplied by PROPUMP Photo 7.1 (b). The PROPUMP pump can run in dry conditions and with low power consumption.



(a) **(b)**

Photo 7.1 Improved bio-pumps

The temperature monitors (T1 and T2) are installed in Tanks 2 and 3 and linked to HP1 and HP2 through a temperature relay. The temperature relay will switch on the hot water pump when required. The hot water temperature inside the urn itself is set only ten degrees higher than the requirement of the bio mass temperature in the digestion tank. This ensures the energy efficiency within the system.

The stirrer in Tank 2 includes a gear motor (YG 2734), a threaded rod and a paddle, Figure 7.13. The motor is controlled by a timer relay to run for 15 minutes every hour.

The float relay F, Figure 7.12 (b), links the contactor inside the transfer container with BP2. When the mass in the container increases to half full, the floating relay will switch BP2 on.

For safety reasons and easy maintenance, all of the relays and power switches were installed in one control box (Photo 7.2). A pair of "busbars" were installed inside the box, Photo 7.2 (a). One bar is for all of the negative connections (black wire) and the other is for all of the positive connections (red wire) Photo 7.2 (b).

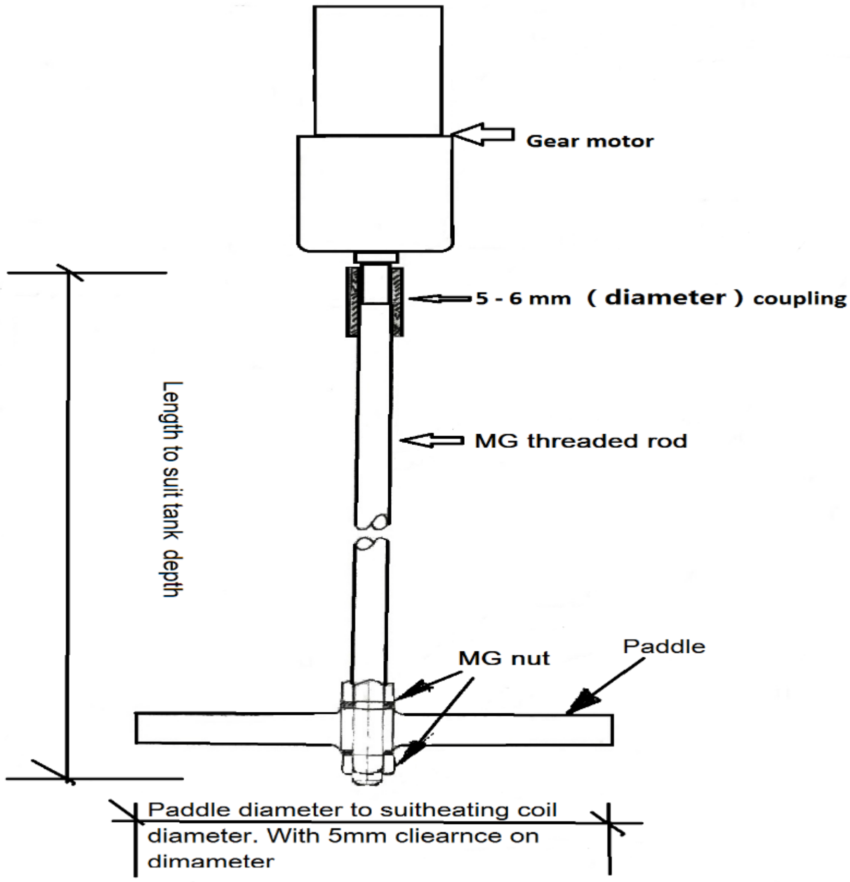
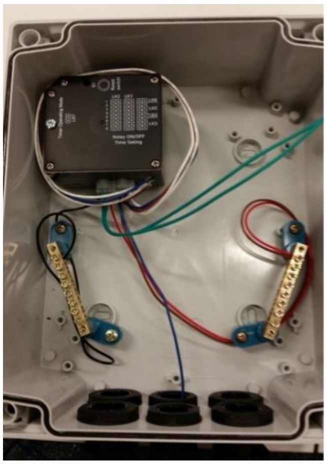
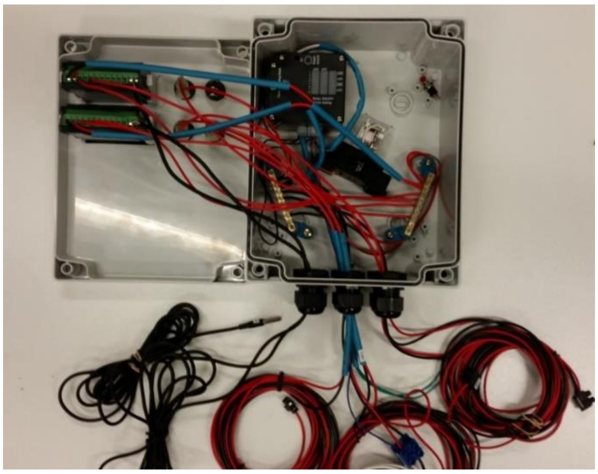


Figure7.13 Details of the paddle stirrer





(a) **(b)**

Photo 7.2 The control box. **(a)** the busbar setting and **(b)** wire layout inside the control box

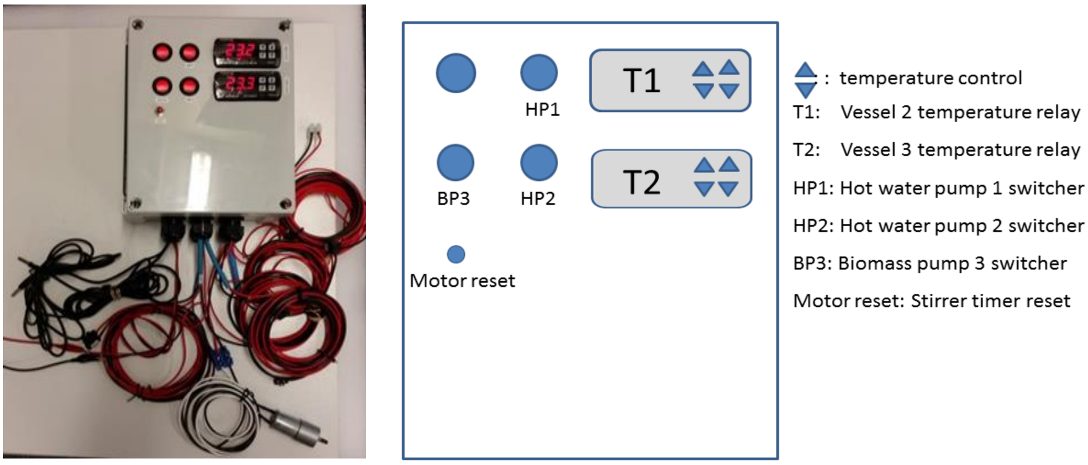


Figure7.14 The control panel

(iv) Gas collection apparatus

The gas collection system includes three individual gas collection units, Photo 7.3. Each unit is fed by a 5 mm PV tube from **Tanks 2, 3** and the **Transfer Vessel,** respectively. The units are comprised of two components (gas and water storage) which utilize physical decompression and water seal principles, Figure 7.4. The gas volume is measured in the gas component plus in the space of each tank. The gas sample is released into the fume hood by the end of the gas tube that links to the tap on top of the gas component.

In order to avoid steam directly entering the gas tube during the fermentation and decomposition of biomass, under thermal conditions (above room temperature), a U shape outflow tube, Photo 7.4 (g), was installed at each gas outlet point inside **Tanks 2** and **3**.

Photo 7.3 Gas collection units

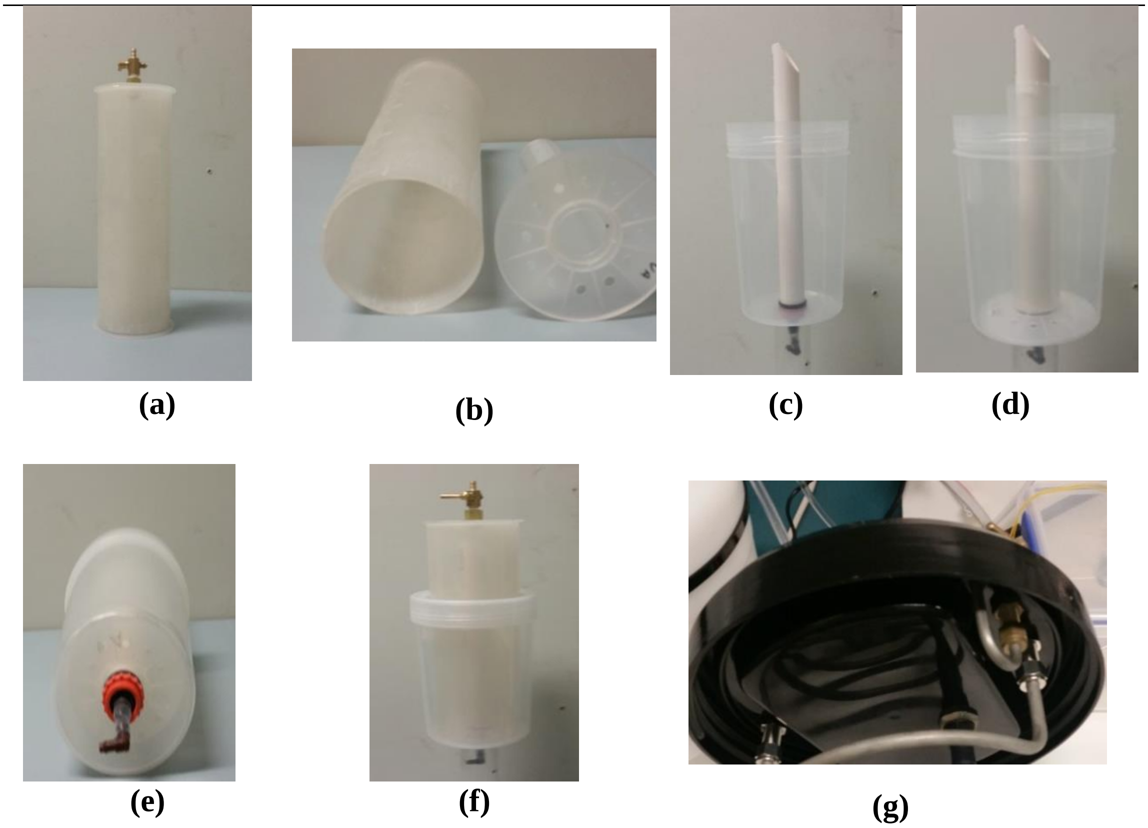


Photo 7.4 Biogas collection unit components **(a)** 500 mL graduated cylinder with gas release valve; **(b)** 500 mL graduated cylinder with (glued) base component; **(c)** outfit and water container with PVC tube for gas flow guide; **(d)** outfit with graduated cylinder base component that suit to the gas flow guide of PVC tube; **(e)** the bottom of the gas collector; **(f)** finished gas collection units and **(g)** the gas outflow component installed with the lid of tanks.

7.3 Commissioning

Testing the electrical system: All the electrical components were individually tested by a qualified electrician. The temperature relays were set to automatic control which allowed the hot water pumps to start the circulation of hot water when the temperature of contents dropped below a predetermined level and to be switched off when the temperature exceeded a certain value, see Chapter 8[20]. The timer for the stirring motor is set to run for 15 minutes per hour. However, it was possible to reset the timer during the course of the experiment.

[20] The operation temperatures setting will be dependent the introduced inoculate of each experiment which are 55 °C and 39 °C in this thesis.

Testing the digestion and heating system: Testing for leakages in all connecting points of the digestion and heating systems was carried out. This step involved injecting 6 L of water into **Tank 1** and then allowing the water to flow into **Tank 2**. After the water reached the outlet point of **Tank 2**, it was allowed to run into the **Transfer Vessel**. When the water reached the float contact, bio pump 2 switched on allowing the water to be pumped into **Tank 3** and subsequently out of the system. During the test all leaks could be sealed using either hose clamps or water-proof silicon.

Testing the gas collection system: The bio-gas collection system check included checking for gas leakage and volume calibration. The bio-gas storage comprised several units – the collection unit, **Tank 2, 3** and the **Transfer Vessel**.

7.4 References

Ariunbaatar, J 2014, 'Methods to enhance anaerobic digestion of food waste', PhD thesis, Université Paris-Est, via Star Lge Upec-upem, <https://tel.archives-ouvertes.fr/tel-01206170>.

Australia, E 2010, *Our Code of Ethics*, <www.engineersauatralia.org.au/ethics>.

Curry, N & Pillay, P 2012, 'Biogas prediction and design of a food waste to energy system for the urban environment', *Renewable Energy*, vol. 41, pp. 200-9.

Kythreotou, NF, Georgios; Tassou, Savvas A. 2014, 'A review of simple to scientific models for anaerobic digestion', *Renewable Energy*, vol. 71, pp. 701-14.

Tampio, E, Ervasti, S, Paavola, T, Heaven, S, Banks, C & Rintala, J 2014, 'Anaerobic digestion of autoclaved and untreated food waste', *Waste Manag*, vol. 34, no. 2, pp. 370-7.

Tsang, Y-l 曾 2013, 'Feasibility of a food waste to energy system in high-rise buildings', Master thesis, The University of Hong Kong, <http://hdl.handle.net/10722/194574>.

Ventura, J-RS, Lee, J & Jahng, D 2014, 'A comparative study on the alternating mesophilic and thermophilic two-stage anaerobic digestion of food waste', *J Environ Sci (China)*, vol. 26, no. 6, pp. 1274-83.

Zhang, C, Su, H, Baeyens, J & Tan, T 2014, 'Reviewing the anaerobic digestion of food waste for biogas production', *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 383-92.

Zhang, Q, Hu, J & Lee, D-J 2016, 'Biogas from anaerobic digestion processes: Research updates', *Renewable Energy*.

Chapter 8: Pilot plant experiments - Part I

Pilot plant experiments had been conducted over five separate runs that are described in Chapter 8 (Runs 1 -3) – Part I and Chapter 9 (Runs 4 – 5) – Part II, respectively. Runs 1 – 3 represent preliminary experiments that were followed by the duplicate Runs 4 and 5. The substrate and inoculum characteristics for the Runs are given in Table 8.1.

8.1 Preamble

As stated in Chapter 6, research into the AD of FW, especially with respect to household food waste, (HFW) is still scarce. This could be related to the fact that food waste can contribute to AD reactor failure due to the higher hydrolysis/acidogenesis ratio of FW compared to other waste types (Cogan and Antizar-Ladislao, 2016). Thus when FW is the primary substrate this can lead to irreversible acidification resulting in AD system failure (Wang et al., 2018) and also the fact that FW is a such variable feed. Furthermore, AD has a complex microbiology mainly involving methanogens. Methanogens grow slowly, with each generation cycle being four to six days (G2School, 2017, WU et al., 2014). Ideally, a rich seeding inoculum is required to initiate anaerobic reactions in a reactor (Vanwonterghem et al., 2015, Leung and Wang, 2016). Therefore, the selection of an appropriate seeding inoculum in order to stimulate AD and enhance the methane production rate is an important consideration.

The following describes the composition of the synthetic food waste used, the two inoculums that were trialled, the preliminary experimental set ups for the pilot plant runs and the measurements and sampling protocols that were carried out. This is then followed by a detailed discussion of the results. This then leads into Chapter 9 where duplicate experimental pilot plant Runs are described.

Table 8.1 The substrate and inoculum characteristics of the experiments protocol

Experiment run	Pilot plant (PTn) / Reference unit 1 (C1)	Reference unit 2 (C2)	Reference unit 3 (C3)	Inoculum usage
Run 1	Synthetic FW with particularly size < 0.2 mm, 500g solid wet weight diluted into 2 L with type water	Synthetic FW with particularly size > 0.2 mm, 500g solid wet weight diluted into 2 L with type water	-	-
Run 2	Same with Run 1	-	-	Inoculum from the Lab. (Inoculum-S)
Run 3	Same with Run 1 with TS=12.7 g/L	The residual from Run 2 with TS =24.1g/L	The fresh substrate from the mixing tank of the Yarra Valley Water Waste to Energy Facility that TS=51.0g/L	Inoculum from Yarra Valley Water Waste to Energy Facility. (Inoculum-Y)
Run 4	Synthetic FW with particularly size < 0.2 mm, 500g solid wet weight diluted into 1 L with type water	Synthetic FW that is with higher protein / lower carbohydrate, particularly size < 0.2 mm, 500g solid wet weight diluted into 1 L with type water	Synthetic FW that is with lower protein / higher carbohydrate, particularly size < 0.2 mm, 500g solid wet weight diluted into 1 L with type water	Inoculum-Y
Run 5	Repeat of Run 4	-	-	Inoculum-Y

8.2 Materials

8.2.1 Synthetic FW

All the Runs 1 - 5 used a synthetic FW, the set-up of each run are listed in Table 8.1[21]. This composition was derived from a consideration of the residential survey results of Chapter 4 & 5 and most common food sold in the local super market. For this research, the daily FW input amount has been set at 500 g wet solid weight. This was based on Yarra council's Domestic WasteStream Audit report, also referred in Chapter [illegible] that specifies the daily (in 2014) FW generation per household in Melbourne, Australia, is approximately 500g (All Environmental Concepts 2014).

Table 8.2 The composition of the synthetic FW used for these experiments.The parameters for the individual components are also given.

FW composition (Item Name and ID Number)		Weight (g, in wet)	Percentage (% in wet)	Typical physiochemical characteristics			
				pH *	Protein (g)**	Fat (g)**	Carbohydrates (g)**
Fruits and vegetables (66%)	Banana	55	11	4.5-5.2	0.66	0.33	12.56
	Broccoli	55	11	6.3-6.5	1.6	--	2.88
	Carrots	55	11	5.3-5.6	0.51	0.16	5.27
	Cauliflower	55	11	5.6-6.5	1.05	--	2.73
	Cucumber	15	2	5.1-5.9	0.1	0.02	0.55
	Lettuce	25	1	5.8-6.2	0.23	0.02	0.74
	Potato	55	11	5.0-5.9	1.41	0.38	6.84
	Tomato	25	5	4.3-4.9	0.22	0.08	0.97
Starch (17%)	Pasta/rice (cooked)	40	8	5.8-6.4	3.12	0.48	30.8
	Bakery	40	8	5.0-6.2	3.08	0.72	21.54
Protein (17%)	Meat/bean (cooked)	55	11	5.6-6.5	19.96	10.12	13.75
	Dairy (dry chees)	25	5	4.1-5.9	0.77	0.87	1.5
Total weight for one feed		500g	100%		30.33	13.18	134.8

* U.S. FDA and the Center for Food Safety and Applied Nutrition
** (United States Department of Agriculture)

[21] For the reference experiments C2 and C3, described in Chapter 9, the composition was adjusted to high protein/low carbon and low protein/high carbon, respectively.

All material, Photo 8.1(a), was purchased from the local supermarket and stored in a cool-room (4 ºC) for no longer than 7 days. According to Izumi et al. (2010) and Moreno-Andrade and Buitron (2015) a FW 'particle size' of between 0.6 - 0.7 mm has the highest methane production. A smaller particle size can reduce the biomass bulk, assist with the breakdown of the lignocellulosic components, increase the surface area of the substrate and bring about more rapid digestion (Kim et al., 2000). However, an ultra-small particle size would also speed up the acidogenesis process and inhibitive the methane production rate (Leung and Wang, 2016). The FW components were mixed according to the percentages as listed in Table 8.2 and blended into a smaller particle size, Photo 8.1(b), using a Nutribullet - 1000 series (made in China). Each 500 g of wet solid mixture was diluted to 2 L with tap water for reactor feed.

(a) **(b)**

Photo 8.1 (a) The components of the synthetic FW for Runs 1 to 3; (b) After blending.

8.2.2 Inoculum

Two different inoculates were employed in these experiments.

1. Inoculum-S was sourced from another research group at VU that has been studying the anaerobic digestion of waste water from the meat industry. Its nutrient composition is listed in Table 8.3. These workers had achieved a methane percentage in their generated biogas of up 60% at a pH of 7.0 at an operation temperature of 55 °C. No microbiological analysis was available for their inoculum.

2. Inoculum-Y was sourced from the AD reactor of the Yarra Valley Water Waste to Energy Facility (Wollert, Victoria). This facility treats food waste from Victorian food industries - with a capacity of 35,000 tonnes per year. It employs four 3,500 m^3 tanks, two of which are for storing plant and meat waste. These feed into a third tank for mixing and fermentation and the final tank is for AD. The inoculum is taken from this tank. This process achieves a methane percentage in the biogas of up to 65% at a pH of 7.6 to 8 at an operation temperature of 39 °C. Again, no microbiological analysis was available for this inoculum.

Table 8.3 The nutrient composition of Inoculum-S

Macro Nutrients		**g/L**
Anhydrous Sodium Acetate	$NaCH_3COOH.3H_20$	1.75
Soy protein		1.75
Glucose	$C_6H_{12}O_6$	5
Urea	CH_4N_2O	0.35
Potassium dihydrogen phosphate	KH_2PO_4	0.5
Magnesium sulphate	$MgSO_4.7H_2O$	0.35
Calcium chloride	$CaCl_2.2H_2O$	0.5
Micro Nutrients (mL)		**0.35**
Iron (III) chloride	$FeCl_3.4H_2O$	1
Cobalt (II) chloride	$CoCl_2.6H_2O$	1
Manganese (II) chloride	$MnCl_2.4H_2O$	0.25
Copper (II) chloride	$CuCl_2.2H_2O$	0.015
Zink chloride	$ZnCl_2$	0.025
Nickel (II) chloride	$NiCl_2.6H_2O$	0.025
Ammonium molybdate	$(NH_4)6Mo_7O_{24}.4H_2O$	0.045
Sodium selenite	$Na_2SeO_3.5H_2O$	0.05
Boric Acid	H_3BO_3	0.025

8.3 Experimental set up and runs

A schematic diagram of the pilot plant (P) is shown in Figure 8.1(a). The operation of P was carried out in the context of the broad experimental design that is shown in Figure 8.2.

Thus three experimental runs were carried out.

Run 1 was carried out with fresh substrate but without any inoculum.

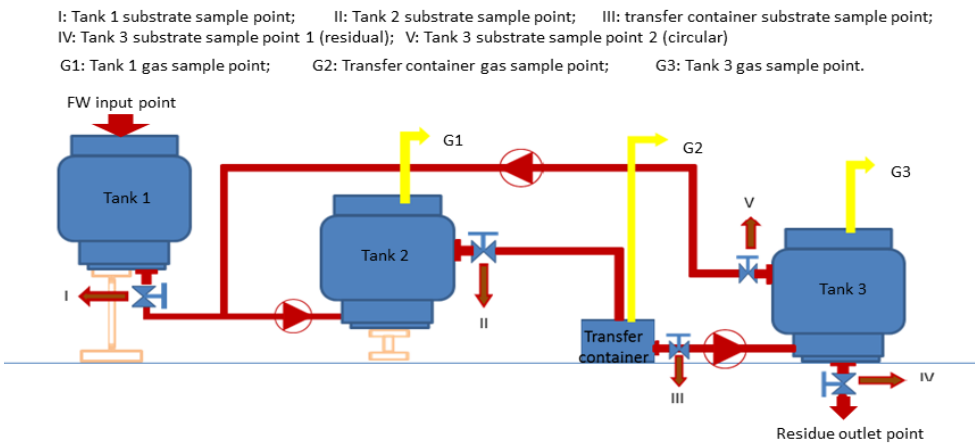
Run 2 was carried out with fresh substrate and Inoculum-S, *vide supra*.

Run 3 was carried out with fresh substrate and Inoculum-Y, *vide supra*.

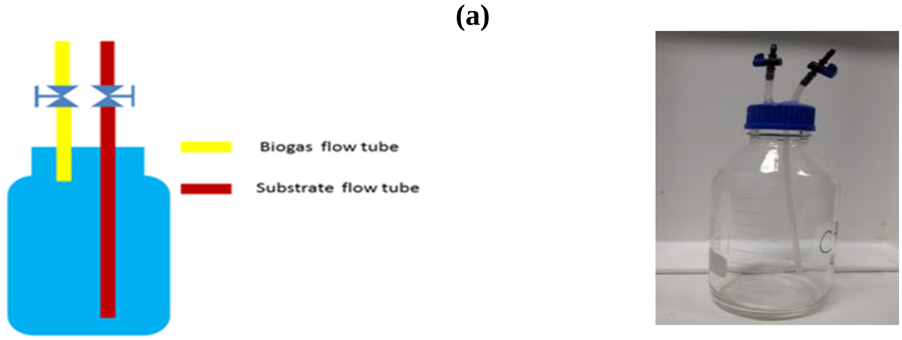
Each experimental run of P was compared to a simple reference set C, Figure 8.1 (b). C is a 1 L bottle connected with two tubes, one for gas outlet and another one for FW input (that it is also the substrate sampling point). The purpose of C is to establish a basic benchmark for the pilot plant.

P, itself, incorporates three tanks - designated PTn (Pilot-plant Tank number = 1, 2, 3). PT1 is used for feedstock storage and is aerobic. PT2 and PT3 are anaerobic digestion tanks and involve biogas generation.

Each run used the equivalent of seven days of FW overall, i.e. 500 g/day, as estimated in Chapter 5, and the equivalent of an extra day of FW was retained in PT1 to ensure that air is not drawn into PT2. This method can also maximize the transfer of any anaerobic bacteria from PT1 to PT2[22].



(a)



(b)

Figure 8.1 Experimental set up and sampling points I – V. Illustration, (a) pilot plant P and (b) reference unit C

[22] https://en.wikipedia.org/wiki/Anaerobic_organism

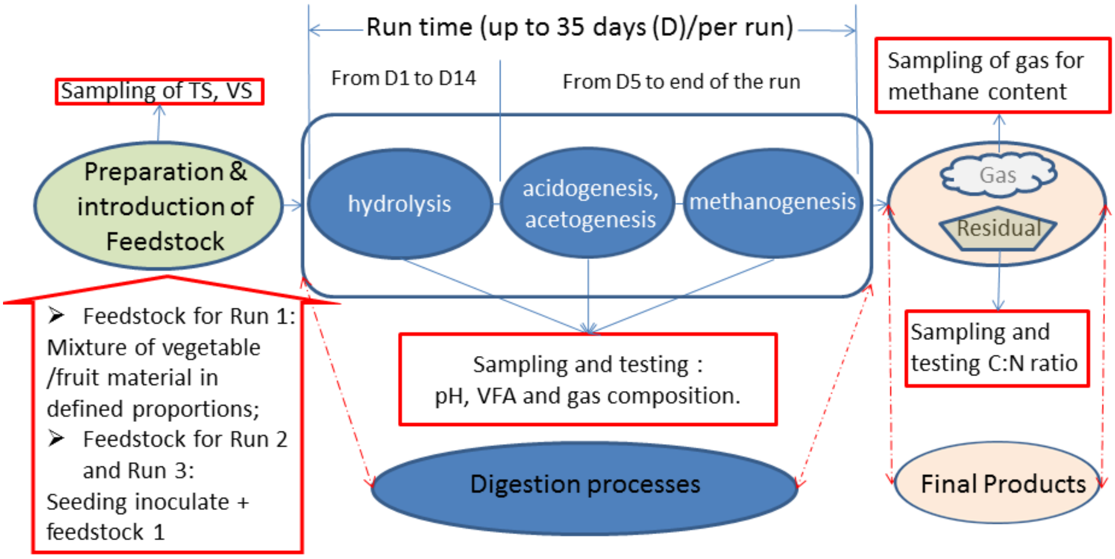


Figure 8.2 Schematic of experiment plan

As shown in Figure 8.2, each Run of the pilot plant was conducted for up to 35 days (see Tables 8.3 and 8.4). Tables 8.4 and 8.5 summarize the feeding regimen with appropriate dilutions, inoculate introductions (apart from Run 1) and cumulative quantities and volumes. Four days' feed amount of FW was fed into PT1 on Day 1 and left until Day 5 before transferring into PT2. From Days 1 to 5 the FW went through the acidification/ pre-fermentation process phase (Peces et al., 2016, Wang et al., 2018). Meanwhile, the selected inoculum was fed into PT2 directly together with a small amount of the FW in order to ensure that the seeding methanogens were introduced gradually. A ratio of 2.9 (inoculum to daily FW feedstock amount by volume) is used for these experiments, as guided by the work of (Hobbs et al., 2017).

The general procedure was as follows:

- Day 1 - The initial "feeding" into PT1 used the equivalent of four days of FW (diluted to 2L).
- Day 2 – 1450 mL of the inoculum was introduced into PT2 combined with 500 mL of the substrate from PT1.
- Day 3 - 500 mL of substrate is transferred from PT1 to PT2.
- Day 4 - 1000 mL of substrate is transferred from PT1 to PT2.

- Day 5 - 2000 mL of substrate is transferred from PT1 to PT2 and 2000 mL of fresh substrate is introduced into PT1.
- Day 6 - 2000 mL of substrate is transferred from PT1 to PT2 and 2000 mL of fresh substrate is introduced into PT1.
- Day 7 - 2000 mL of substrate is transferred from PT1 to PT2 and 2000 mL of fresh substrate is introduced into PT1. 1450 mL of substrate is transferred from PT2 into the Transfer Container.
- Day 8, Day 9 and Day 10 – 2000 mL of substrate is transferred from PT1 to PT2. 2000 mL of substrate is transferred from PT2 into the Transfer Container. 2000 mL of substrate is transferred from the Transfer Container into PT3.
- Day 11 - 1000 mL of substrate is transferred from PT2 into the Transfer Container. 1000 mL of substrate is transferred from the Transfer Container into PT3.
- After Day 11 until the end of the experimental run, the amount of substrate in each tank and in the Transfer Container is kept constant.

The reference unit C used the same feeding method, but the feedstock amount is 10% of the amount used for P. For C, from Day 8 to Day 11, before inputting fresh FW, the same amount of residual was extracted. After Day 12, 700 mL of substrate remained in C.

8.4 Sampling and parameter analysis

Substrate samples were collected from the P sampling points I to IV, Figure 8.1 (a), from the start to the end of each Run. The planned sampling schedules for the different tests are listed in Table 8.6 and Table 8.7. However, these were varied somewhat during the actual Runs - details will be discussed in Section 8.5 - Results and Discussion. Substrate samples were stored at 4 °C until analysis. TS, TVS, pH, VFA of both substrate and inoculum and the composition and volume of biogas were measured. The actual methods of testing are described later.

TS, TVS and pH

For the TS test, three 5mL samples of the mixed substrate were taken and was filtered under vacuum using a glass fibre filter (pore size 45 μm), the filter residue with filter paper in small aluminium alloy tray (a) were then placed in dry-oven at a temperature of 105° C for one hour. Then cooled to room temperature and weighed to constant weight.

TVS test was then employed by heating at 550 °C for 1 h then cool down to room temperature as well.

During this process, recorded the weighs of the glass-fibre filter paper with aluminium alloy tray (a), the glass-fibre filter paper with aluminium alloy tray and the filter residue after dried at 105°C (b) and the glass-fibre filter paper with aluminium alloy tray and the filter residue after dried at 550°C (c). Then calculated the TS and TVS of the substrate for sample. TS is the weight of b - a (TS = b - a), and TVS is the TS - c - a (TVS = TS − Residual)(APHA 1998).

The pH was measured when the sample was taken (Checker HANNA).

VFA

Volatile fatty acids (VFAs) are short chain fatty acids containing 2-6 carbon atoms. In biological processes these VFAs are significant intermediates produced by acidogenesis. The existence of VFAs in a sample usually indicates biological activity due to the presence of a range of microorganisms. Therefore, VFA can be used as an important operational parameter to control and manage the anaerobic digestion process (Lee et al., 2015) .

A high VFA concentration is typically an indication of process instability (Zhang et al., 2017b). In this research, ten VFAs have been detected; namely, acetic, propanoic, iso-butyric, butyric, iso-valeric, valeric, isocaproic, hexanoic and n-heptanoic acids. However, as indicated in Figure 6.1 in Chapter 6, acetic, propionic, butyric and valeric acids are the major VFAs relevant to the methanogenesis of FW (Wang et al., 2018). Therefore, these are the only VFA considered for analysis in this study.

To determine the various volatile fatty acid concentrations, a Shimazdu GC – 2010 Gas Chromatograph, equipped with a flame ionisation detector (FID), a SGE BP20 column (12 m x 0.22 mm internal diameter x 0.25 µm film thickness) and an auto sampler, were used as Instrument Operation Guide. Concentrations have been expressed in ppm.

Biogas monitor and analysis

Biogas was taken daily from the gas holder of P, Figure 8.3 (a), and from the gas bag of C, Figure 8.3 (b), then fed into a Biogas 5000 gas analyser (Gas Geotech) to determine the biogas composition.

Table 8.4 FW and inoculum feeding amount and frequency in each experiment run of PT. Notes: g*n denotes the number of grams of FW over n days. The volume of inoculum for Run 1 is zero.

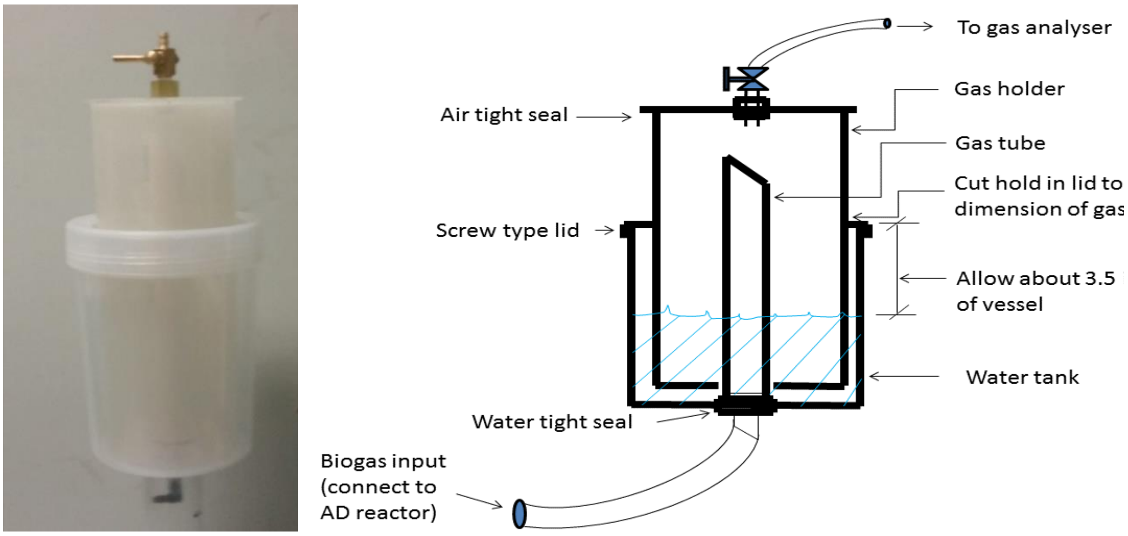
Day	1	2	3	4	5	6	7	8	9 to 35
FW	500 g*4	-	-	-	500 g*1	500 g*1	500 g*1	500 g*1	-
Water	1500 mL*4	-	-	-	1500 mL*1	1500 mL*1	1500 mL*1	1500 mL*1	-
Inoculum	-	1450 mL	-	-	-	-	-	-	-
Sub-total	8000 mL				2000 mL	2000 mL	2000 mL	2000 mL	-
Total in feedstock	8000 mL	9450 mL	9450 mL	9450 mL	11450 mL	13450 mL	15450 mL	17450 mL	

Table 8.5 The amount (mL) of substrate in different tanks in each experiment run of PT

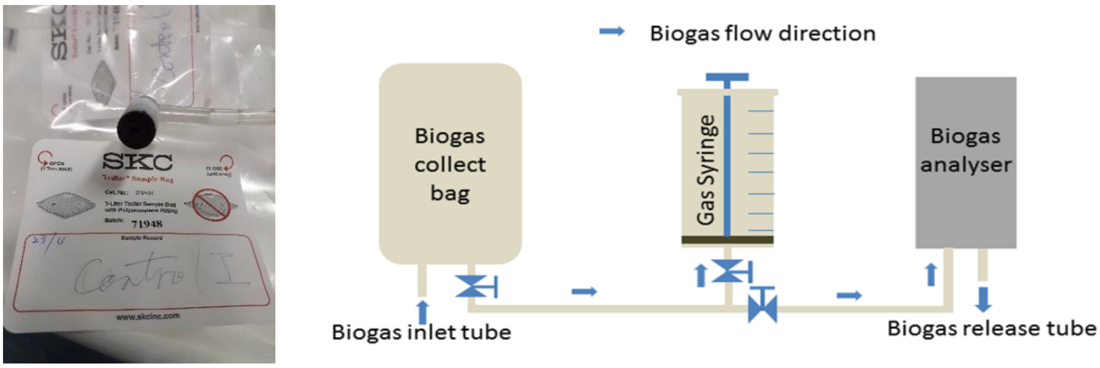
Day	1	2	3	4	5	6	7	8	9	10	11 to 35
Tank 1	8000	7500	7000	6000	6000	6000	6000	6000	4000	2000	2000
Tank 2	-	1950	2450	3450	5450	7450	8000	8000	8000	8000	7000
Transfer							1450	1450	1450	1450	1450
Tank 3	-	-	-	-	-	-	-	2000	4000	6000	7000

Table 8.6 The sampling schedule and testing for the Pilot Plant PTn (mL taken is indicated)

Point* / Time	PT1	PT2	PT3
Day1	TS, TVS, pH, VFA, C:N (50 mL)		-
Day 3	TS, TVS, pH, VFA, C:N (feedstock as same with CI) (40 mL)	TS, TVS, pH, VFA, C:N (50 mL)	-
Day 7		TS, TVS, VFA, (25 mL)	TS, TVS, VFA, (25 mL)
Day 11-27 (every two days)		VFA (5 mL)	VFA
End of the run	-	TS, TVS, C:N (45 mL)	TS, TVS, C:N (45 mL)



(a)



(b)

Figure 8.3 Biogas collection (a) P gas collection unit (b) C gas collection bag.

Table 8.7 The sampling schedule and testing for the Reference Unit (Cn) (mL taken is indicated)

Time \ Point**	C1	C2	C3
Day 3	TS, TVS, pH, VFA, C:N (feedstock as same with PT1) (40 mL)	TS, TVS, pH, VFA, C:N (feedstock) (40 mL)	TS, TVS, pH, VFA, C:N (feedstock) (40 mL)
Day 7	TS, TVS, VFA, (15 mL) (used data in SI)	TS, TVS, VFA, (15 mL)	TS, TVS, VFA, (15 mL)
Day 11 – 27 (every two days)	VFA (5 mL)	VFA (5 mL)	VFA (5 mL)
End of run	TS, TVS, C:N (30 mL)	TS, TVS, C:N (30 mL)	TS,TVS, C:N (30 mL)

8.5 Results and discussion

8.5.1 Run 1

The purpose of Run1 was to test whether AD occurs at all in the absence of an inoculum, whilst operating at room temperature within a given time frame. Both P and C had been employed for these experiments. For P, one particle size of feedstock was used, whereas for C, two particle sizes of feedstock were used. Inside P and C1, the feedstock was < 0.5 mm - prepared via Nutribullet and, inside C2, the feedstock was 0.5 to 2 mm - prepared through a normal kitchen food blender, Photo 8.2.

Run 1 (for P, C1 and C2) started on the 11/08/2017 and was ended on the 28/08/2017 (17 days) with no resultant AD, which could be seen from the severe acidification of the substrates (Table 8.8 and Figure 8.4) and with no biogas generation. Ideally, if AD was occurring, the pH trend would resemble that shown in Figure 8.5 (Sundberg, 2005). Note, the achievement of a high pH of around 8 occurs approximately six days after the minimum.

The total absence of AD was highlighted by C1 and C2 remaining effectively unchanged until the present time, Photo 8.2.

Table 8.8 The pH values of experiments

Dayth	1st	3rd	5th	7th	11th	13th	18th
PT1	5.7	4.0	4.0	4.3	3.4	3.3	3.3
PT2					3.4	3.3	3.6
C1	5.7	4.0	4.0	3.7		3.4	3.3
C2	5.7	4.5	4.0	3.7		3.4	3.4

Photo 8.2 Reference set of Run 1: left is C1 and right is C2

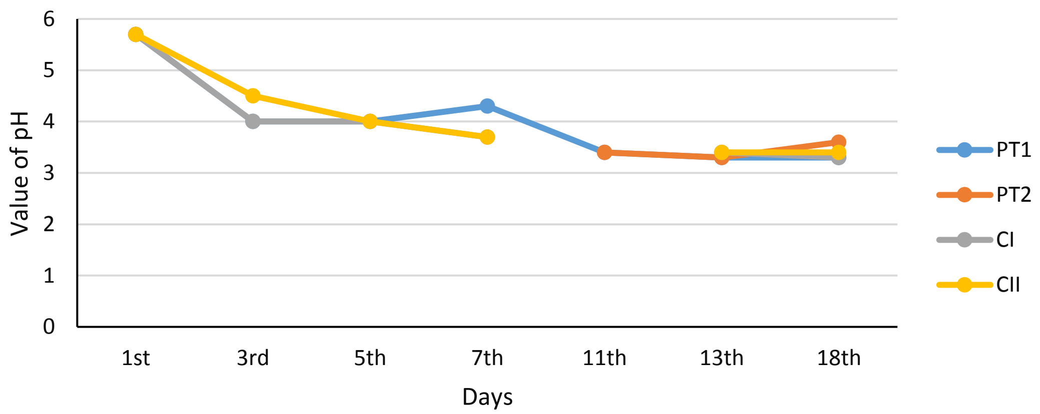


Figure 8.4 The pH trends of P, C1 and C2 over Run1

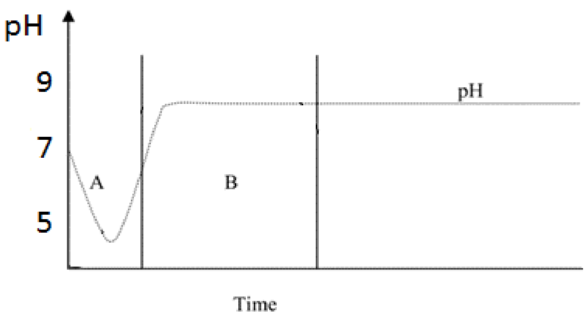
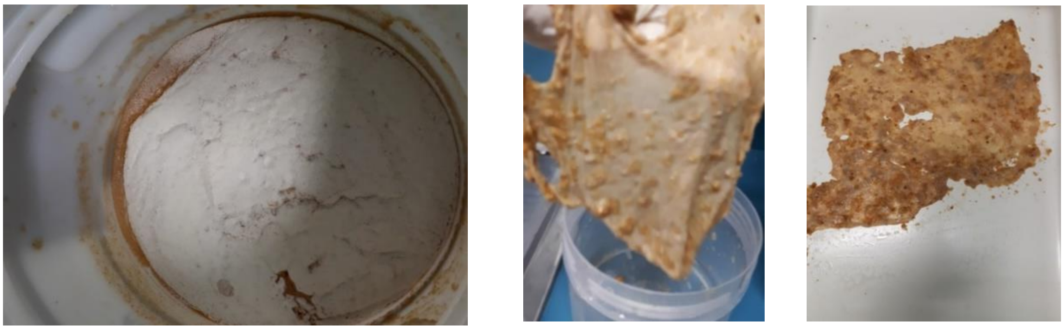


Figure 8.5 The pH value developing trend

With respect to P, during the Run, a large piece of fungus was formed on top of the substrate in PT1, Photo 8.3. There was no obvious dark fermentation process occurring in PT2 which is the essential step during AD (De Gioannis et al., 2013, Cavinato et al., 2012, Micolucci, 2014)[23]. The nature of this fungal material has not been pursued in this thesis although it is deemed to be of interest.



(a) **(b)** **(c)**

Photo 8.3 Fungus in PT1: (a) inside PT1; (b) removed by the experimenter and (c) dried out fungus

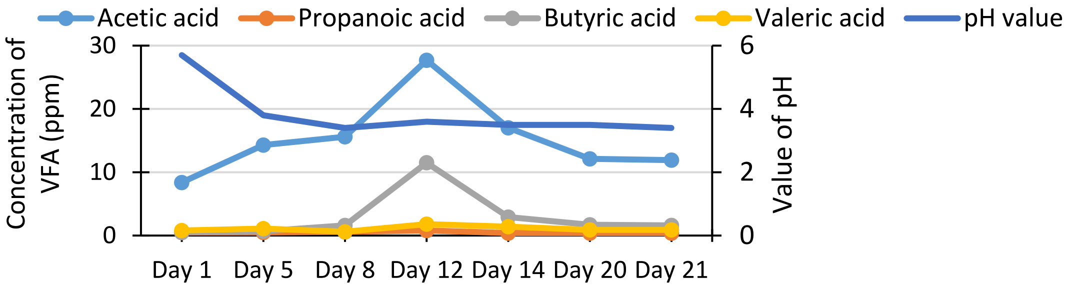
8.5.2 Run 2

This run was conducted to test whether the introduction of Inoculum-S into P could initiate and/or sustain the AD of the FW. Since this inoculum was previously shown to be effective (in its other application) at a temperature of 55 ^{o}C, P was also operated at this temperature. This was facilitated by the heating elements incorporated into the design of P, see Figure 7.4 and section of Chapter 7.2.2.2 - II. For C, the units were immersed in the hot water bath at a temperature of 55 ^{o}C. Run 2 started on 26/10/2017 and ended on 18/12/2017. Here, as with Run 1, there was no apparent AD process and the pH levelled out to between 3 and 4 for both PT1 and PT2, Figure 8.6 (details given in Appendix 8.1).

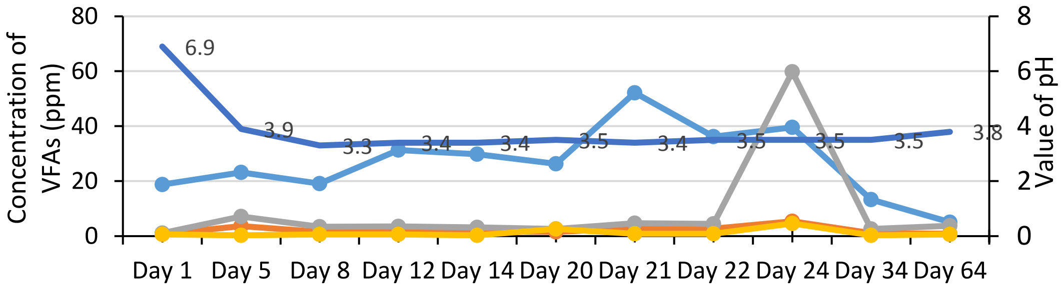
Figure 8.6 shows that, during the process, acetic acid was the major VFA produced, both under aerobic (PT1) and anaerobic (PT2) conditions. In PT1, the acetic acid concentration slowly increased from day 1 and peaked on day 12, and then declined until day 21 to a level that was slightly higher than the initial concentration. Butyric acid started to emerge from day 8 and peaked on day 12, declining to near zero by day 21. Within PT2, the average value of the acetic acid concentration was approximately twice that of PT1 within

[23] The colour change associated with AD ("dark fermentation") can be seen through the walls of the pilot plant tanks.

same period time and peaked on day 21, declining to near zero by day 64. Butyric acid started to emerge significantly on day 22 and peaked on day 24, declining to near zero on day 34. The peak lags between PT1 and PT2 are likely to be related to the frequency of substrate input. The trends towards the lower pH values reflect the acid production in both PT1 and PT2. Notably, there was no effort made in this Run to control the pH, e.g. by buffering. Therefore, the acidic conditions that are obviously present throughout the run were not conducive to the survival of anaerobic organisms. This situation was addressed (successfully) in Run 3 as described below.



(a) PT1



(b) PT2

Figure 8.6 The value of pH and VFA developing trend

8.5.3 Run 3

This run was conducted to test whether an appropriate control of pH via dosing would result in the AD of FW. For this purpose, a dosing apparatus was incorporated into P, see Photo 8.4. For this run it was necessary to use Inoculum-Y since Inoculum-S became unavailable. Since this inoculum was previously shown to be effective (in its other application) at a temperature of 39 ^oC, P was also operated at this temperature.

The results of Run 1 and Run 2 suggest that acidification is the major obstacle to AD. Therefore, alkaline solution dosing has been introduced into Run 3. The alkaline solution that was used was 1M NaOH. Two automatic dosing pumps and pH monitors were thus installed in PT1 and PT2 respectively, Photo 8.4. The values of the pH were set at 6 in PT1 (aerobic) and 8 (anaerobic) in PT2. Also, a stirrer with an automatic control motor was installed in PT1 and the stir time for PT2 was adjusted to ensure a quick adjustment of the pH after the addition of the alkaline solution.

Run 3 started on the 31/03/2018 (with a first feed into PT1) and the last sampling day was on the 04/05/2018 (PT2 and reference units C1, C2 and C3). During this run, the TS value for PT1/2 was 12.7 g/L. It was decided to examine the possible effect of varying this via the reference units C1 to C3. Thus the TS values for these units were 12.7, 24.1 and 51.0 g/L respectively. These three feed stocks came from three different source. For PT1/2 and C1, fresh synthetic FW of the composition listed in Table 8.1 was used. C2 reused the residual from Run 2 and C3 used the substrate from the mixing tank of the Yarra Valley Water Waste to Energy Facility.

In Run 3, the pH of the raw feedstock was adjusted to 6 in PT1. The first feed into PT1 (under aerobic conditions) was for n days' worth. The second feed was on day five and the remainder as showed in Table 8.3. For PT2, a quarter of the daily amount was supplied for the first four days and for the fifth day a full daily amount was supplied and then, after that, a full daily amount every two days, Table 8.4. This method was chosen in an attempt to reduce excess easily degradable organic compounds, accelerate dark fermentation and avoid pH shock so as to encourage a higher buffering capacity for the appropriate anaerobic microbes (Charles et al., 2009, Peces et al., 2016, Wang et al., 2018).

The overall data from Run 3 is represented in Figure 8.7. It is clear that for this run, the chosen conditions result in a sustained generation of methane gas over a period of approximately two weeks, from day 20 to day 35. Over this period, the average methane composition was 63%, ranging from 50.4% to 70.1%. The all-important average pH over this time was 8.0, with a range of 7.7 to 8.3. Prior to the relatively high methane production period, where the feedstock is actually being added to P, there is still a level of methane production occurring, albeit at a lower rate - with an average composition of around 24 %. This is consistent with the results of (Wang et al., 2018) in that the active phase of methane production was from Day 5 to 33, after the acidogenesis stage (from Day 1 to 5).

The pH over this time averages around 7.9. It was clear from the results of this run that the stringent pH control, together with an appropriate inoculum, could result in a sustained production of methane for P.

Other data represented in Figure 8.7 include the VFA levels over the run period. Thus, the VFAs are generated up to day 22 and then they cannot be detected for the remainder of the run, although notably the methane production remains vigorous until the end of the run. This suggests that there is sufficient sustenance of the anaerobic bacteria to function for up to two weeks *after* the VFA production has dropped to zero.

It is possible that these microorganisms are obtaining sustenance from more than just fatty acids, e.g. from sugars or polysaccharides or proteins, peptides and amino acids. This aspect of the research obviously requires further investigation.

8.5.4 A comparison of the PT2 Run 3 with C1 to C3

It was mentioned previously that the three reference units C1 to C3 were run in parallel to P with C1, C2 and C3 having TS values for the FW of 12.7 (same as PT2), 24.1 and 51.0 g/L respectively, *vide supra*. Figures 8.8 and 8.9 compare the relevant data for PT2, C1, C2 and C3 in relation to the variation in TS. The average pH values of 8, 7.8, 7.8 and 7.6 respectively suggest that the pH tends to decrease with increasing TS, although this does not appear to influence the methane production. In terms of VFA production, it may be observed that PT2 and C1 are similar with all the VFAs peaking with the first 20 days. Thus for PT2 propanoic and butyric acids peak on day 14 and acetic and valeric acid peak on day 20. However, for C1, all VFAs peak on day 14. This could be due to the difference in stirring between these two units. In both cases, the VFAs drop to zero after 24 days, even though the methane production continues. For C2 the VFA production peaks early on around day 5 for all VFAs and slightly peaks on day 22. This can be explained by the fact that the FW for C2 was the residual from Run 2. Here, there is no fatty acid production after day 24. For C3, the VFA production peaks on day 14 with minor peaks on day 20 and 22. Thus it is very similar to PT2 and C1. There is no VFA production after day 24, again in spite of a continuing methane generation (up to day 35). Indeed, across all of these units there was sustained methane generation as may be observed in Figure 8.9, at levels of up to 70%.

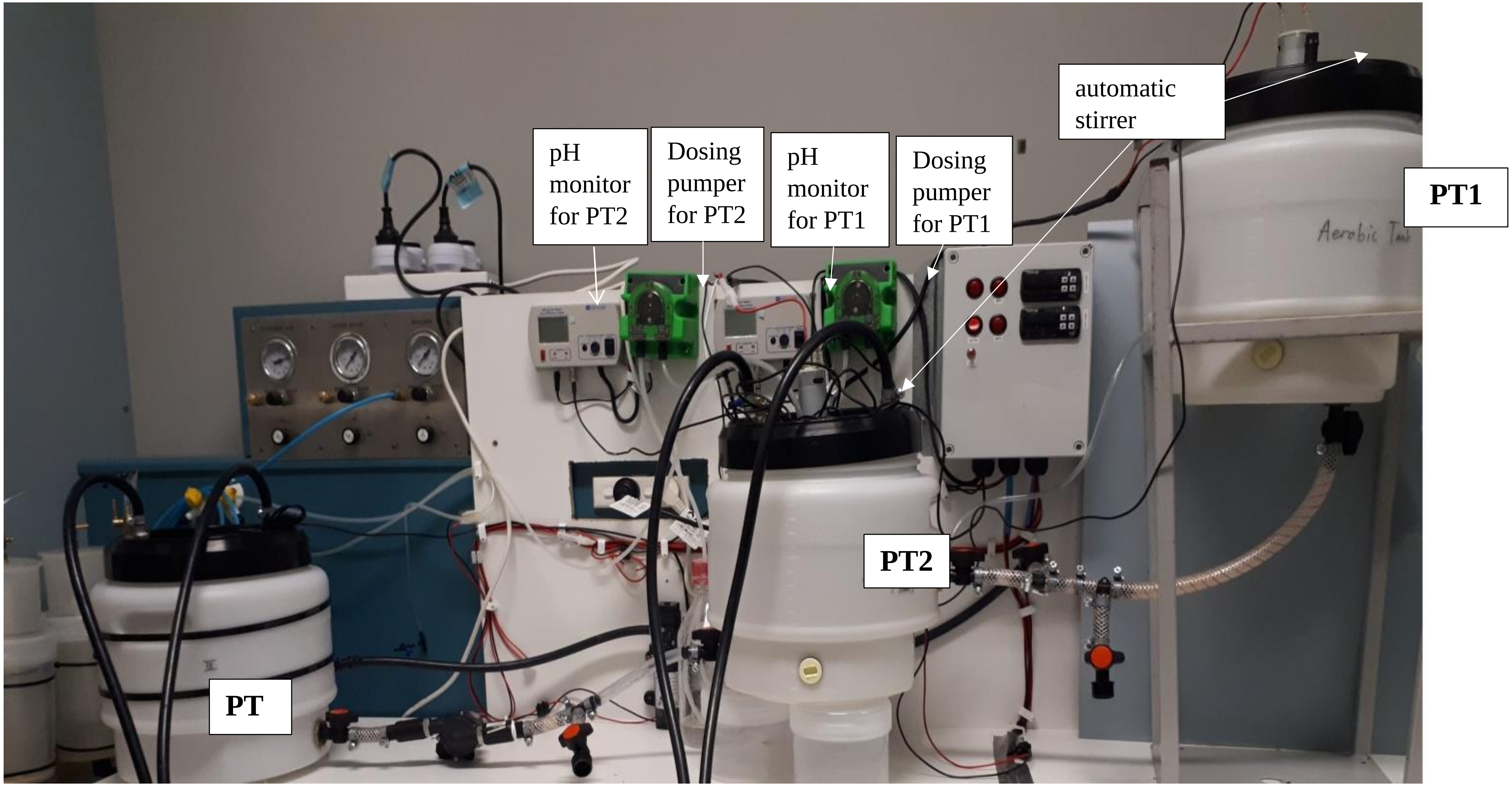
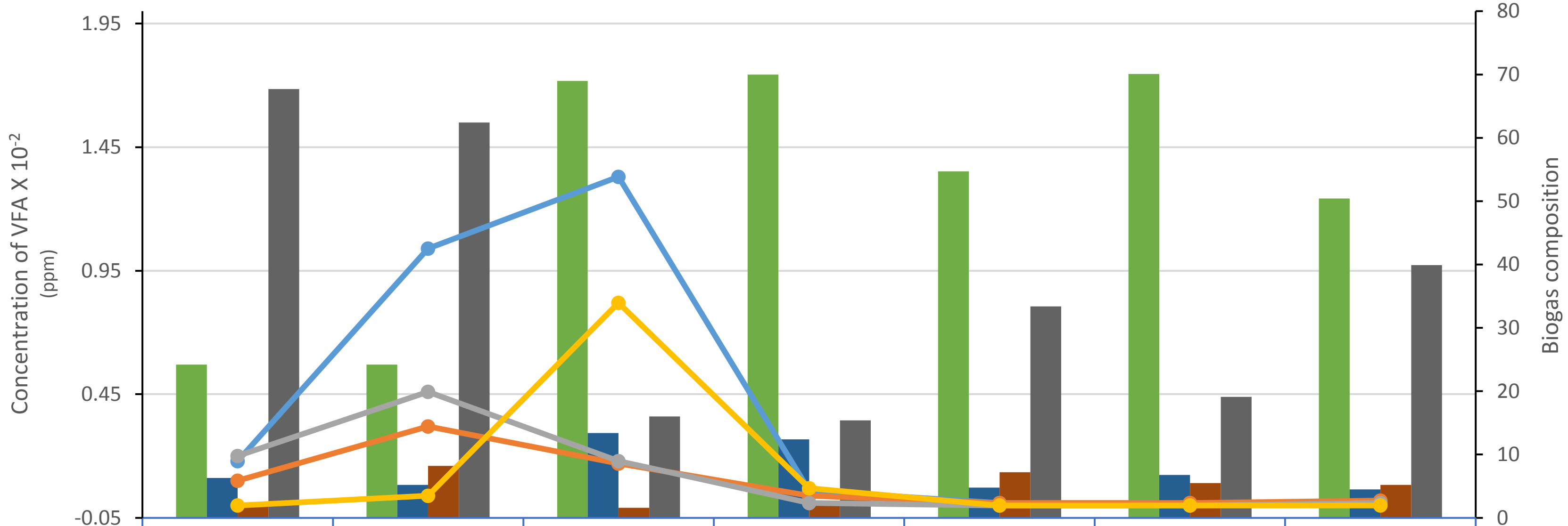


Photo 8.4 The pilot plant with two pH automatic dosing pumps (the green color of parts installed in back white panel) and automatic control motor installed in PT1



	Day 5	Day 14	Day 20	Day 22	Day 24	Day 25	Day 35
CH4 (%)	24.2	24.2	69	70	54.7	70.1	50.4
CO2 (%)	6.3	5.2	13.4	12.4	4.8	6.8	4.5
O2 (%)	2.1	8.2	1.6	2.3	7.2	5.5	5.2
Balance (%)	67.7	62.4	16	15.4	33.4	19.1	39.9
Acetic acid	0.18	1.04	1.33	0.06	0.01	0.01	0.01
Propanoic acid	0.1	0.32	0.17	0.04	0.01	0.01	0.02
Butyric acid	0.2	0.46	0.18	0.01	0	0	0.01
Valeric Acid	0	0.04	0.82	0.07	0	0	0
pH value	7.8	7.9	8	7.7	8.3	8	8

Figure 8.7 The data from Run 3 over time for the pilot plant P. All data was sourced from the anaerobic tank PT2. The balance of biogas was mostly N_2 and very small amounts of other gases, such as CO, H_2S and H_2. Note: the VFA concentrations are expressed as ppm x 10^{-2}.

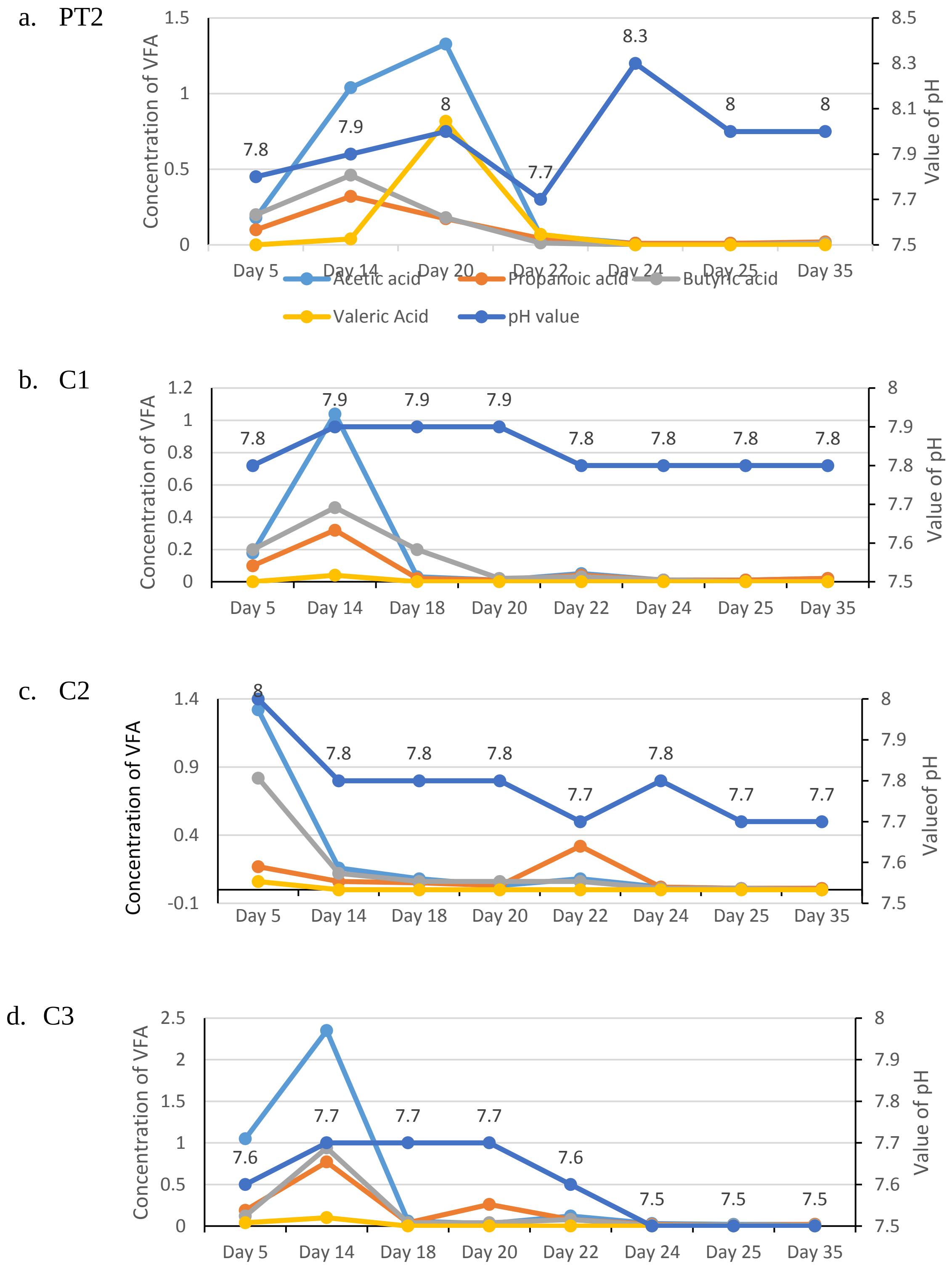


Figure 8.8 The value of pH and major 4 VFA developing trend of AD process in PT2 and three reference units (the data detail for reference units see Appendix 8.2)

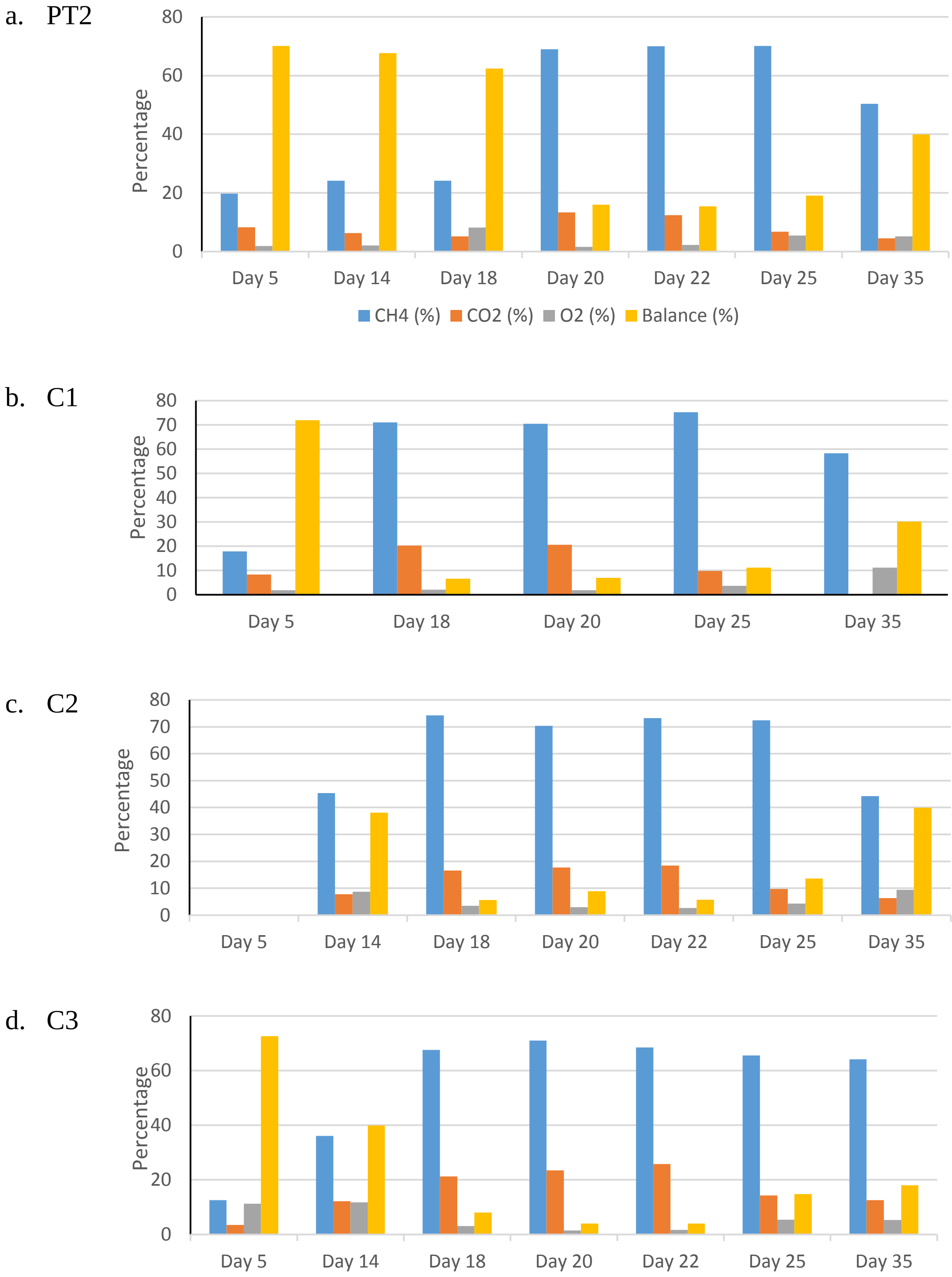


Figure 8.9 The bio-gas that generated from PT and references units (the data detail for reference units see Appendix 8.3)

8.6 Comments

- The results were consistent with an appropriate anaerobic inoculum being essential for the AD of FW (Charles et al., 2009). Two such inoculums were used here from different sources. However, it was not possible to carry out a detailed comparison between the relative effectiveness of these due to limitations on time and resources. Some studies for future work would include a detailed comparison of the effect of their relative microbial compositions on methane production. It is also apparent from our investigations that strict pH control is required, outlined as follows.

- Minimal acidification during start-up and a high buffering capacity of the substrate provides the required environment for methane production. It has been demonstrated that maintaining a pH of ~ 8 in the anaerobic tanks favours a sustained methane production of up to 70%.

- An interesting phenomenon has been observed, whereby up to ~ Day 22, there is a surge of VFA production in the anaerobic PT2. During this time period there is a steady build-up of methane production to a maximum composition of 70% that is sustained for up to 35 days. Notably, the VFA production falls to effectively zero after the initial surge. This suggests that a proper understanding of the role of VFAs in the AD process is required. Thus the VFA concentrations can be used along with other operational parameters to control and manage the anaerobic digestion process. One question that needs to be addressed is the optimum VFA concentration range in relation to methane production (Zhang et al., 2017b, Ren et al., 2018, Lee et al., 2015, Algapani et al., 2017) . The balance between VFA production and consumption plays a key role in anaerobic digestion performance.

8.7 References

Algapani, DE, Wang, J, Qiao, W, Su, M, Goglio, A, Wandera, SM, Jiang, M, Pan, X, Zi, K, Adani, F & Dong, R 2017, 'Improving methane production and anaerobic digestion stability of food waste by extracting lipids and mixing it with sewage sludge', *Bioresource Technology*.

All Environmental Concepts 2014, *City of Yarra Domestic Waste Stream Audit, Garbage & Recycling*, Yarra City Council.

Cavinato, C, Giuliano, A, Bolzonella, D, Pavan, P & Cecchi, F 2012, 'Bio-hythane production from food waste by dark fermentation coupled with anaerobic digestion process: A long-term pilot scale experience', *International Journal of Hydrogen Energy*, vol. 37, no. 15, pp. 11549-55.

Charles, W, Walker, L & Cord-Ruwisch, R 2009, 'Effect of pre-aeration and inoculum on the start-up of batch thermophilic anaerobic digestion of municipal solid waste', *Bioresource Technology*, vol. 100, no. 8, pp. 2329-35.

Cogan, M & Antizar-Ladislao, B 2016, 'The ability of macroalgae to stabilise and optimise the anaerobic digestion of household food waste', *Biomass and Bioenergy*, vol. 86, pp. 146-55.

De Gioannis, G, Muntoni, A, Polettini, A & Pomi, R 2013, 'A review of dark fermentative hydrogen production from biodegradable municipal waste fractions', *Waste Management*, vol. 33, no. 6, pp. 1345-61.

G2School 2017, *厌氧活性污泥法生物处理废水*, viewed 01/09 2017, <(http://cc.jlu.edu.cn/G2S/Template/View.aspx?courseId=40&topMenuId=117822&action=view&type=1&name=&menuType=1&curfolid=117870)>.

Hobbs, SR, Landis, AE, Rittmann, BE, Young, MN & Parameswaran, P 2017, 'Enhancing anaerobic digestion of food waste through biochemical methane potential assays at different substrate: inoculum ratios', *Waste Management*, no. 2017, p. 6.

Izumi, K, Okishio, Y-k, Nagao, N, Niwa, C, Yamamoto, S & Toda, T 2010, 'Effects of particle size on anaerobic digestion of food waste', *International Biodeterioration & Biodegradation*, vol. 64, no. 7, pp. 601-8.

Kim, I, Kim, D & Hyun, S 2000, 'Effect of particle size and sodium ion concentration on anaerobic thermophilic food waste digestion', *Water Science and Technology*, vol. 41, no. 3, pp. 67-73.

Lee, D-J, Lee, S-Y, Bae, J-S, Kang, J-G, Kim, K-H, Rhee, S-S, Park, J-H, Cho, J-S, Chung, J & Seo, D-C 2015, 'Effect of Volatile Fatty Acid Concentration on Anaerobic Degradation Rate from Field Anaerobic Digestion Facilities Treating Food Waste Leachate in South Korea', *Journal of Chemistry*, vol. 2015, p. 9.

Leung, DYC & Wang, J 2016, 'An overview on biogas generation from anaerobic digestion of food waste', *International Journal of Green Energy*, vol. 13, no. 2, pp. 119-31.

Micolucci, FG, M.; Bolzonella, D.; Pavan, P. 2014, 'Automatic process control for stable bio-hythane production in two-phase thermophilic anaerobic digestion of food waste', *International Journal of Hydrogen Energy*, vol. 39, no. 31, pp. 17563-72.

Moreno-Andrade, I & Buitron, G 2015, 'Evaluation of particle size and Initial concentration of total solids on Biohydrogen production from food waste', *Fresenius Environ. Bull.*, vol. 24, no. 7, pp. 2289-95.

Peces, M, Astals, S, Clarke, WP & P.D., J 2016, 'Semi-aerobic fermentation as a novel pre-treatment to obtain VFA and increase methane yield from primary sludge', *Bioresource Technology*, vol. 200, no. 2016, p. 8.

Ren, Y, Yu, M, Wu, C, Wang, Q, Gao, M, Huang, Q & Liu, Y 2018, 'A comprehensive review on food waste anaerobic digestion: Research updates and tendencies', *Bioresource Technology*, vol. 247, pp. 1069-76.

Sundberg, C 2005, 'Improving Compost Process Efficiency by Controlling Aeration, Temperature and pH', Swedish University of Agricultural Sciences.

United States Department of Agriculture, ARS *USDA Food Composition Databases*, 29/07/2018, <https://ndb.nal.usda.gov/ndb/search/list? >.

Vanwonterghem, I, Jensen, PD, Rabaey, K & Tyson, GW 2015, 'Temperature and solids retention time control microbial population dynamics and volatile fatty acid production in replicated anaerobic digesters', *Scientific Reports*, vol. 5, p. 8496.

Wang, P, Wang, H, Qiu, Y, Ren, L & Jiang, B 2018, 'Microbial characteristics in anaerobic digestion process of food waste for methane production–A review', *Bioresource Technology*, vol. 248, no. 2018, p. 8.

WU, M, ZHANG, R, ZHOU, J, XIE, X, YONG, X, YAN, Z, GE, M & ZHENG, T 2014, 'Effect of temperature on methanogens metabolic pathway and structures of predominant bacteria', *CIESC Journal*, vol. 65, no. 5, p. 5.

Zhang, J, Loh, K-C, Li, W, Lim, JW, Dai, Y & Tong, YW 2017, 'Three-stage anaerobic digester for food waste', *Applied Energy*, vol. 194, pp. 287-95.

Chapter 9: Pilot plant experiments - Part II

9.1 Preamble

Worldwide, the concern for the sustainability of urbanization is reflected in an enthusiasm for the prospect of energy recovery through the AD of domestic organic waste. Thus, increasing the biogas recovery rate is a major objective in AD process research and the relevant technology design. Such biogas commonly consists of 60-70% methane (CH_4), 30-40% carbon dioxide (CO_2) and small amount of other gases such as nitrogen (N_2), hydrogen (H_2), hydrogen sulphide (H_2S) and ammonia (NH_3) (Jingura and Kamusoko, 2017). However, methane is the primary goal of energy recovery for this project. In this context, the objective of the pilot plant design was to optimize the AD/FW process and to maximize the methane production. This part of the experimental program is based primarily on Run 3 (see Chapter 8) and focuses on the optimization of the methane production.

9.2 Methodology

9.2.1 Experimental set-up

The set-up and data collection/processing scheme for Part II is shown in Figure 9.1. Some preliminary comments relevant to the set-up are provided here and the details are outlined in the subsequent sections.

As shown in Figure 9.1, the Part II experiments have been designed to run according to two scenarios – Scenario I (S-I) involved the pilot plant (PT) itself and involves the three tanks (PT1 to PT3) that service the three stages of the AD process, Figure 9.2. PT1 is aerobic and can also be used for feedstock storage. PT2 and PT3 are both anaerobic for biogas generation. Scenario II (S-II) involves the three independent reference units (C1 to C3) of 1L each, Figure 9.1. Each unit consists of three 1L bottles, C1n, C2n and C3n (n = a, b, c), Figure 9.3.

The PT was further refined for these experiments (Photo 8.4 [previous]/ Figure 9.2 [refined set-up]). In the new set-up, compared to the previous, two automatic pH controllers and two automatic dosing pumps were installed. A stirrer timer was also installed in PT1 in order to maintain the pH balance of the substrate when the dosing pumps were operated, Figure 9.2 (b). The substrate inlet point in PT2, Figure 9.2 (a), is now raised to exploit the gravity/pressure difference, enabling bio-pump 1 to be removed. Also, the Transfer Vessel has been removed reducing the possibility of leakage. All of the new components were tested before the Part II experiments commenced.

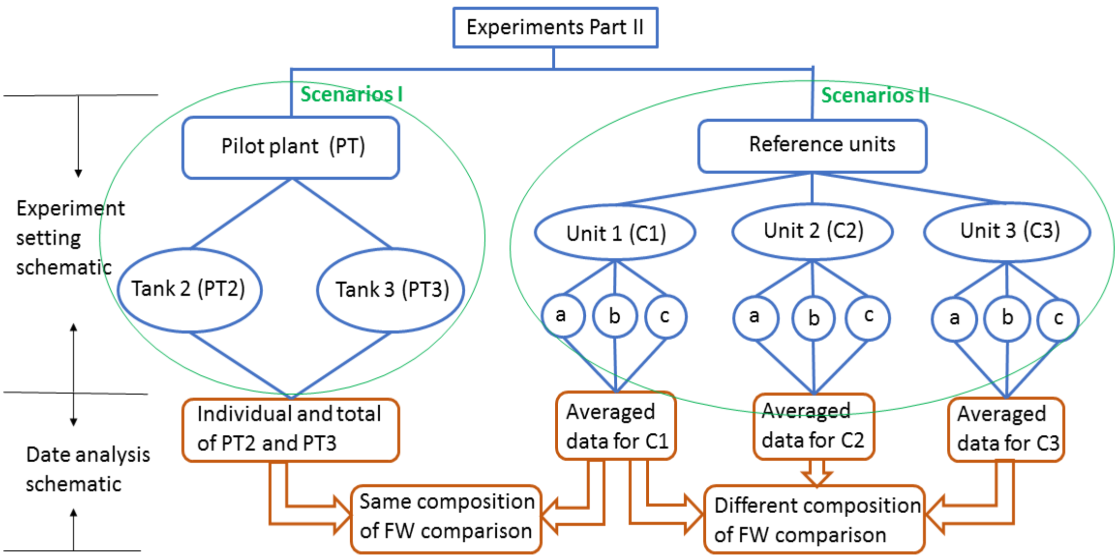
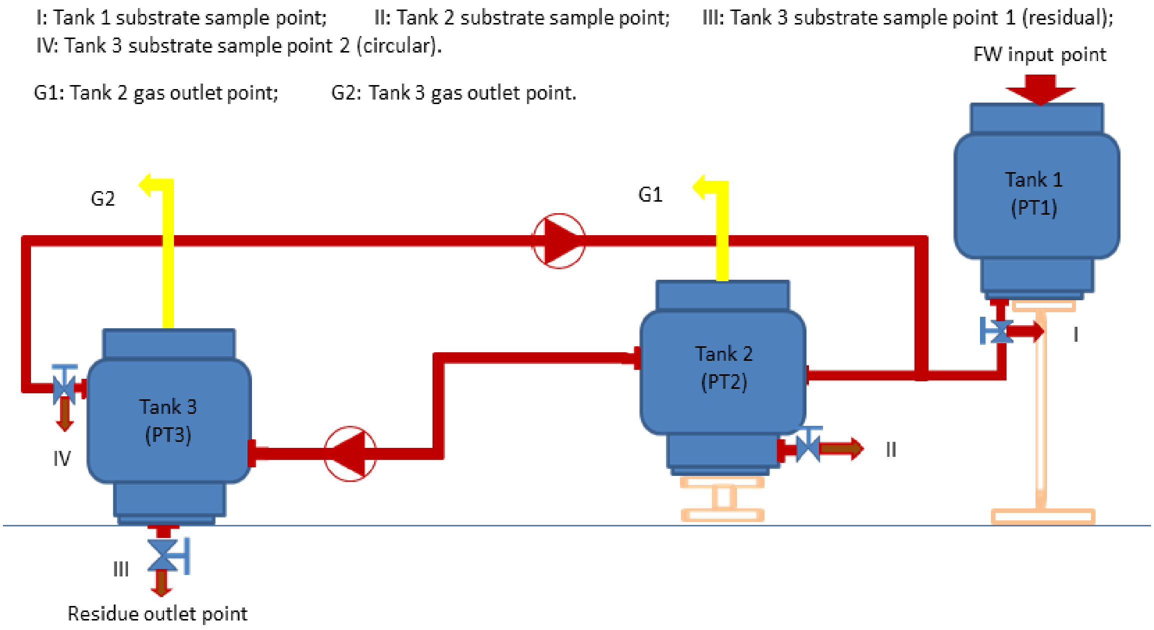


Figure 9. 1 Set-up and data collection/processing scheme for Part II

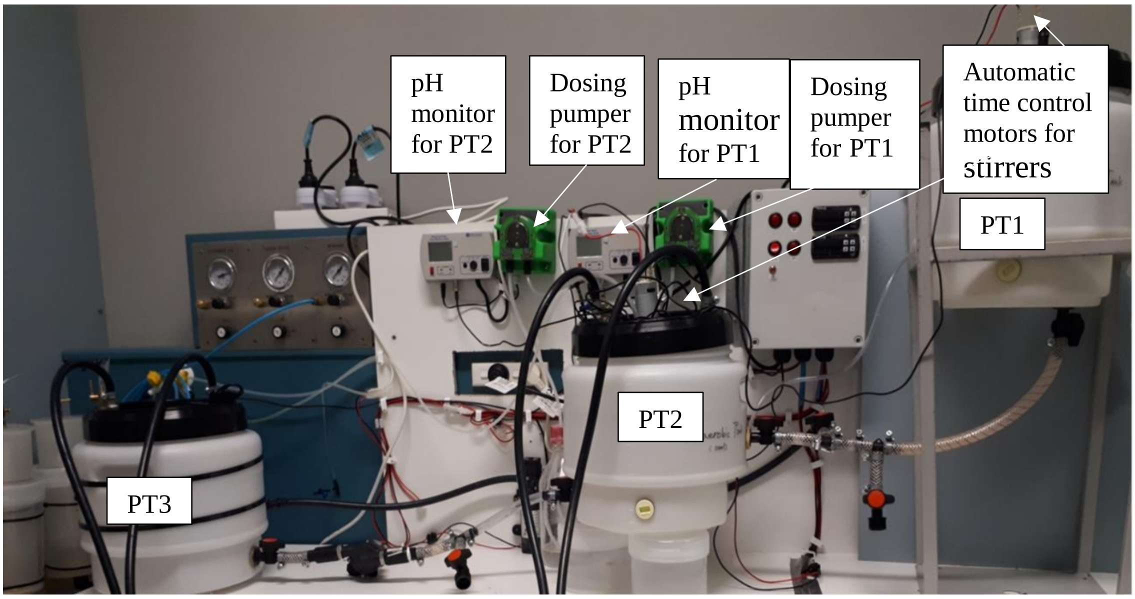
The temperature for the AD experiments in S-I was set at 39 °C (determined by the inoculate -Y used). A hot water bath was used to maintain this temperature for SII.

The pH for both S-I and II was maintained at around 7.6 for the AD experiments. In S-I, this was achieved via two automatic pH control and dosing pumps systems (Milwaukee MC720, Italy) that were originally installed in PT1 (pH at 6 ± 0.1) and PT2 (pH at 7.6 ± 0.1) of SI. Also, two stirrers were installed in PT1 and PT2, respectively, to help maintain a homogeneous pH level within the substrate and to enhance biogas release. These now run for 30 mins per hour at 50 rpm (12VDC Reversible Gearhead Motor - Jaycar Electronics, Australia).

For S-II, the pH of the feedstock is adjusted to ~ 7.6 before injecting into each bottle. pH adjustment used 1M NaOH solution. The bottles were then shaken for one minute and kept at 39 °C in a hot water bath. 1L air bags (Tedlar sample bag) were used to collect biogas generated from C1n, C2n and C3n for S-II and 3L air bags (Tedlar sample bag) were used for PT2 and PT3 for S-I.



(a)



(b)

Figure 9.2 (a) the PT set-up showing sampling points and gas outlet points (b) photo of the PT set-up with new components

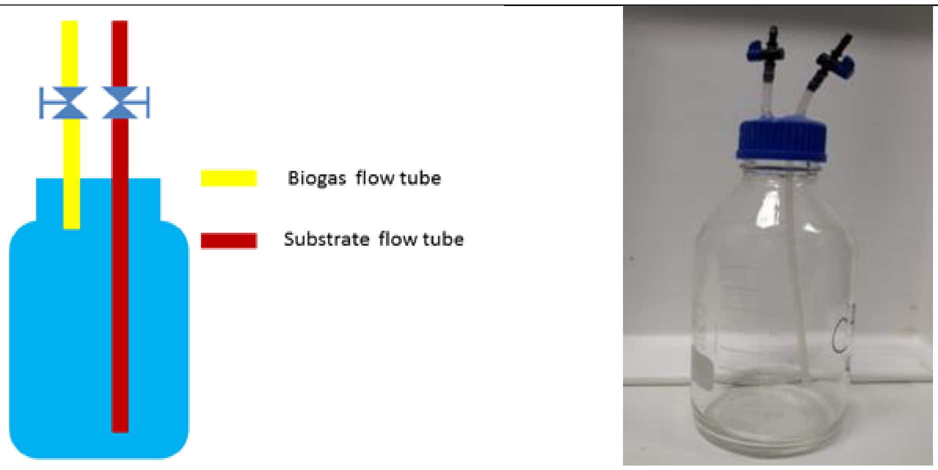


Figure 9.3 SII – Units C1 to C3, representative bottle

9.2.2 Feed stock preparation and organization

In S-I, the composition of synthetic FW feedstock was 66% fruits and vegetables, 17% starchy and 17% protein. This represents an averaged FW composition based on the conclusions of Chapter 4 and 5. Details are listed in Table 9.1.

According to the survey results reported in Chapter 4, the daily FW generation per household in Melbourne, Australia is around 500 g (reference to Chapter 4). Therefore, as for Part 1, the daily FW input amount has been set at 500 g wet solid weight.

There are three different compositions of synthetic FW feedstock for each reference group. In C1, the substrate is same as that used in S-I (Table 9.1). For the other two groups, the substrate uses high protein and low carbohydrate synthetic FW (i.e. 70% meat and 30% vegetable and starchy food) - for C2 (Table 9.2) - and low protein and high carbohydrate synthetic FW (20% meat and 80% vegetable and starchy food) (Table 9.3) - for C3. Table 9.4 shows the protein to carbohydrate ratio of the three reference groups.

All material for the synthetic FW was purchased from a local supermarket. The feedstocks for each scenarios were prepared according to the composition and proportions listed in Tables 9.1, 9.2 and 9.3. For S-I, five serves (5 x 500 g) of feedstock were mixed, blended, diluted with the same weight of tap water and fed into PT1. For S-II, fifteen serves (5 x 3 x 50 g) of feedstock for each of C1, C2, and C3 were mixed, blended, diluted with the same weight of tap water, divided into three and stored in a cool-room (at 4 °C) ready for feeding into the reference units. All the feedstock was blended into fine particles [Nutribullet (1000W, China)] - with a 30 second run time. This procedure was repeated once more after a five day interval. Before putting the feedstock into S-I and S-II, all the feedstock was pre-treated by the addition of 1M NaOH to give a pH of 7.8 (which was found to give the highest CH_4 composition in R3), Figure 9.4.

The inoculum in Part 2 was collected from a mesophilic anaerobic digester, processing food waste at the Yarra Water AD plant and was stored in sterilised plastic containers for transportation to our laboratory (takes ca. 50 min). Upon arrival, the inoculum was passed through a 1.6 mm mesh sieve, then 4,000 mL was injected into PT2 and 400 mL aliquots were injected into the nine units of SII. All the units then were sealed and flushed with nitrogen for 5 min each.

Table 9.1 The composition and proportion of synthetic FW used for the pilot plant (PT) (one-service） and reference group 1(C1) (10% of amount of PT)

FW composition (Item Name)		**Weight (g, in wet)**	**Percentage (% in wet)**	**Typical physiochemical characteristics**		
				pH *	**Protein (g/100g) ****	**Carbohydrates (g/100g)****
Fruits and vegetables type (66%)	Banana	55	11	4.5-5.2	0.6 (1.09)	12.56 (22.84)
	Broccoli	55	11	6.3-6.5	1.6 (2.98)	2.88 (5.24)
	Carrots	55	11	5.3-5.6	0.51 (0.93)	5.27 (9.58)
	Cauliflower	55	11	5.6-6.5	1.05 (1.92)	2.73 (4.97)
	Cucumber	15	3	5.1-5.9	0.1 (0.65)	0.55 (3.63)
	Lettuce	25	5	5.8-6.2	0.23 (0.9)	0.74 (2.97)
	Potato	55	11	5.0-5.9	1.41 (2.57)	6.84 (12.44)
	Tomato	25	5	4.3-4.9	0.22 (0.88)	0.97 (3.89)
Starchy type (17%)	Pasta (cooked)	40	8	5.8-6.4	1.75 (4.37)	10.05 (25.12)
	Bread	40	8	5.0-6.2	3.08 (7.69)	21.54 (53.85)
Protein type (17%)	Chicken minced	55	11	5.6-6.5	9.59 (17.44)	0.02 (0.04)
	Soy bean (cooked)	25	5	4.1-5.9	2.66 (10.62)	3.44 (13.75)
In total		500g	100%		22.8	67.59

* U.S. FDA and the Center for Food Safety and Applied Nutrition
** (United States Department of Agriculture)

Table 9.2 The composition and proportion of synthetic FW used for reference unit 2 (C2) (one-service)

FW composition (Item Name)		Raw Weight (g, in wet)	Percentage (% in wet)	Typical physiochemical characteristics		
				pH *	Protein (g/100g)**	Carbohydrates (g/100g)**
Fruits and vegetables type (20%)	Cauliflower	5	10	5.6-6.5	0.1 (1.92)	0.25 (4.97)
	Cucumber	5	10	5.1-5.9	0.03 (0.65)	0.18 (3.63)
Starchy type (10%)	Pasta (cooked)	5	10	5.8-6.4	0.22 (4.37)	1.26 (25.12)
Protein type (70 %)	Chicken minced	35	70	5.6-6.5	6.1 (17.44)	0.01 (0.04)
In total		50g	100%		6.45	1.7

Table 9.3 The composition and proportion of synthetic FW used for the reference unit 3 (C3) (one-service)

FW composition (Item Name)		Weight (g, in wet)	Percentage (% in wet)	Typical physiochemical characteristics		
				pH *	Protein (g/100g) **	Carbohydrates (g/100g)**
Fruits and vegetables type (30%)	Banana	5	10	4.5-5.2	0.06 (1.09)	1.14 (22.84)
	Broccoli	5	10	6.3-6.5	0.15 (2.98)	0.26 (5.24)
	Carrots	5	10	5.3-5.6	0.05 (0.93)	0.48 (9.58)
Starchy type (50%)	Steamed rice	15	10	5.8-6.4	0.48 (3.20)	5.08 (33.88)
	Bread	10	10	5.0-6.2	0.77 (7.69)	5.39 (53.85)
Protein type (20%)	Chicken minced	10	20	5.6-6.5	1.74 (17.44)	- (0.04)
In total		50g	100%		3.25	12.35

Table 9.4 The composition ratios of the three reference groups, C1 to C3

Composition of synthetic FW	Reference group 1 (C1) (See Chapter 5, same as the pilot plant)	Reference group 2 (C2) (High protein, low carbohydrate)	Reference group 3 (C3) (low protein, high carbohydrate)
Protein to carbohydrate ratio	0.34	3.8	0.26

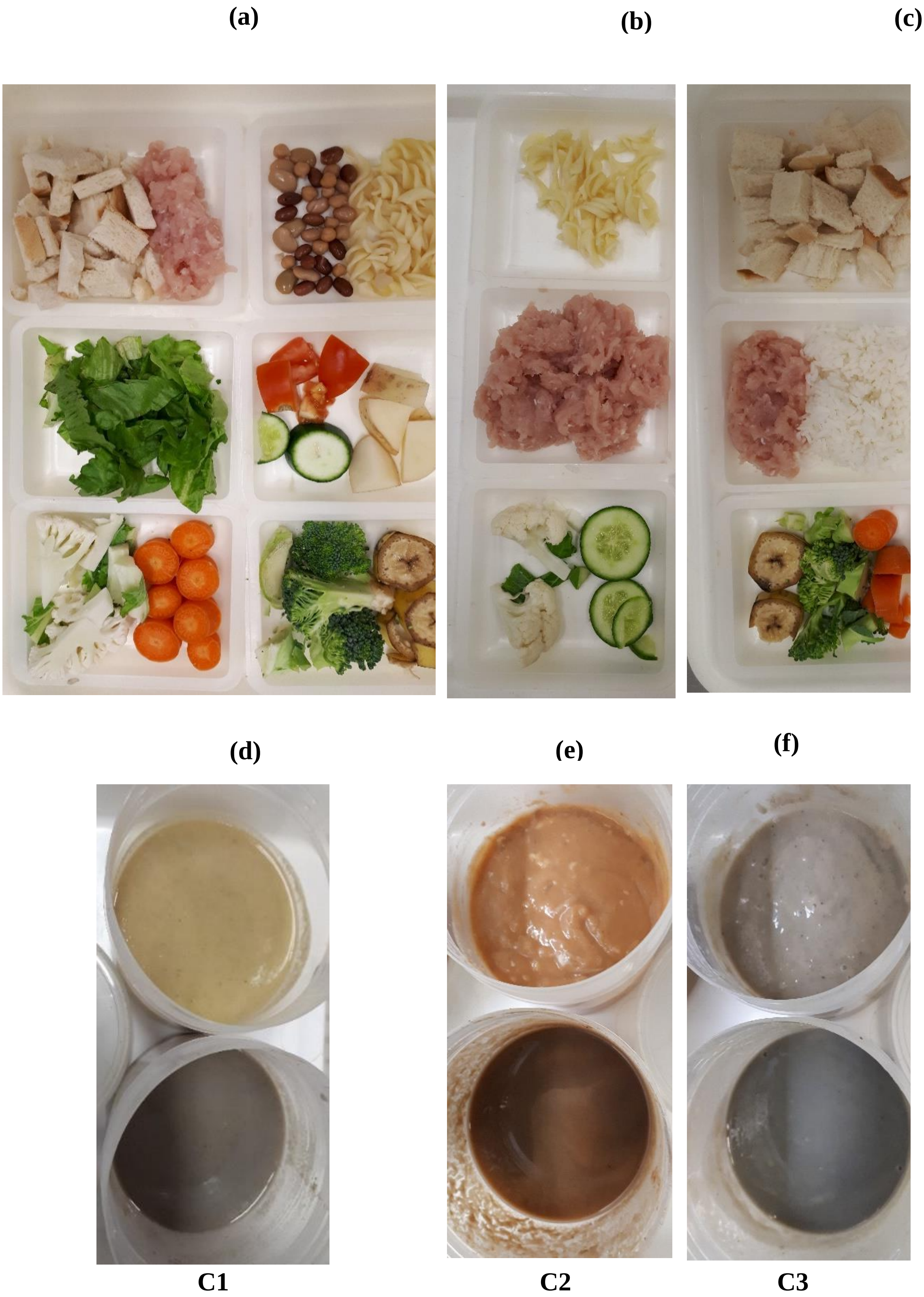


Figure 9.4 Feedstock pre-treatment**:** (a), (b) and (c) represent the three difference raw feedstocks for PT/C1, C2 and C3, respectively. (d), (e) and (f) represent (top photo), each raw feedstock finely blended, (bottom photo) each treated with 1M NaOH to a pH of 7.8.

9.2.3 Feeding model and time frame

The synthetic FW was fed batch-wise once every two days from day 5 to day 20. Table 9.5 shows the FW's feeding schedule.

For S-II, from day 15, 100 mL of the substrate was taken out from each unit before new FW feedstock was put into the unit, Table 9.6. This was to allow sufficient space and to better reflect the pilot plant conditions.

Due to time constraints, the time allowed for each experiment did not allow for the full decomposition of the FW. Therefore, the timeframe for these experiments was designed to allow for 4 to 5 methanogen lifespans (Zhang, Lan-ying (张兰英) et al., (2005) stated that the generation methanogen cycle is approx. 6 days).

9.2.4 Parameter testing

In this experiment the total solids (TS), total volatile solids (TVS), volatile fatty acids (VFA), the carbon to nitrogen ratio (C:N) of the substrate and the volume and composition of biogas were the major parameters for testing. A schematic of the experiment plan showed in Figure 9.5.

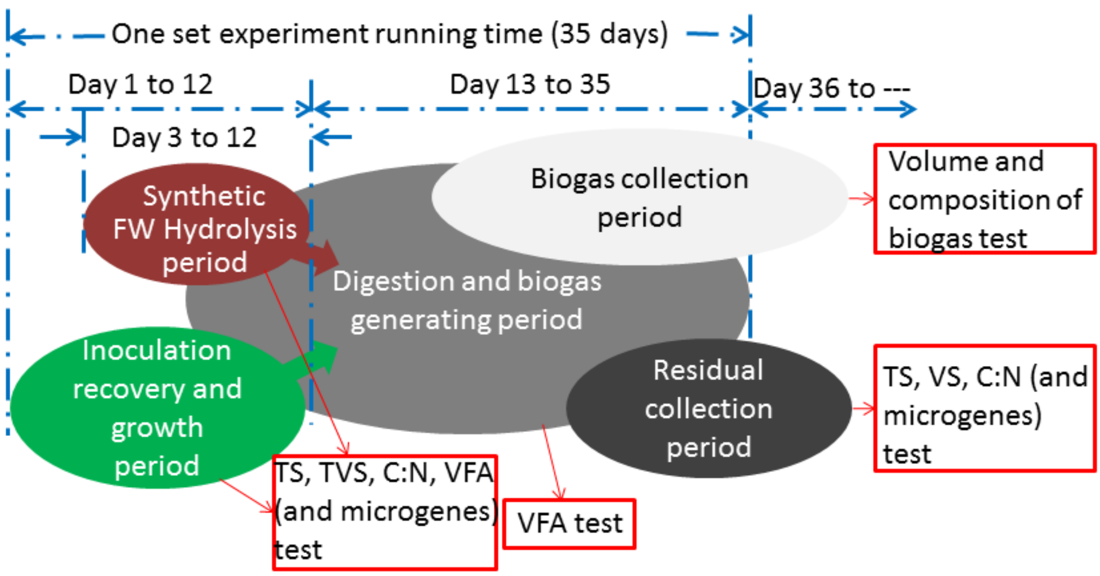


Figure 9.5 Schematic time frame and relevant testing items of experiment part 2

Table 9.5 FW and inoculum feeding frequency (day), feeding and holding amount (mL) in each units of SI during experiment

	1	3	5	7	9	11	13	15	17	19	21	23	25
PT1 holding amount	5,000	3,000	1,000	5,000	3,000	1,000							
Inoculum amount	4,000		-	-	-	-	-						
FW amount input into PT2 from PT1	2,000	2,000	2,000	2,000	2,000	2,000	1,000						
PT2 holding amount	6,000	8,000	10,000	10,000	10,000	10,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000
PT3 holding amount				2,000	4,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Total Substrate in SI (PT2+PT3)	6,000	8,000	10,000	12,000	14,000	16,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000

Table 9.6 FW and inoculum feeding frequency (day), feeding and holding amount (mL) in each unit of SII during experiment

Day	1	3	5	7	9	11	13	15	17	19	21	23	25
Inoculum amount	200		-	-	-	-	-						
Substrate in each unit (inoculant + FW)	300	400	500	600	700	800	900	900	900	900	900	900	900
Residual withdraw each time								100	100	100	100	100	100
Residual withdraw in total								100	200	300	400	500	600

9.2.4.1 Sampling frequency and size

TS, TVS and C:N were tested in the feedstock, inoculant and final residual for PT2 of SI, C1n, C2n and C3n of SII and the first day feed substrate of PT3 for SI. The VFA was tested in days 1, 6, 12, 18, 24, 30, 33 and 40. The biogas collection started on day 13 then every two days at the same time to ensure the consistency.

The sampling schedule and total sample size for each unit for the different tests are listed in Tables 9.7 and 9.8.

Substrate samples were stored at 4 °C and bio-gas samples were kept in airbags at room temperature until analysis.

Table 9.7 Sampling schedule and sample sizes for substrate tests with S-I

Point* / Time	PT1	PT2	PT3
Day1	TS, TVS, pH and VFA (50ml)		-
Day 3	TS, TVS, pH and VFA (feedstock as same with CI) (40mL	TS, TVS, pH and VFA (50mL)	-
Day 7		TS, TVS, and VFA (25mL	TS, TVS, and VFA (25mL)
Day 11-27 (every two days)		VFA (5mL)	VFA
Day 35	-	TS and TVS (45mL)	TS and TVS (45mL)

Table 9.8 Sampling schedule and sample sizes for substrate tests with S-II

Point** / Time	C1	C2	C3
Day 3	TS, TVS, pH and VFA (feedstock as same with PT1) (40mL)	TS, TVS, pH and VFA (feedstock) (40mL)	TS, TVS, pH and VFA (feedstock) (40mL)
Day 7	TS, TVS and VFA (15mL) (used data in S-I)	TS, TVS and VFA (15mL)	TS, TVS and VFA (15mL)
Day 11 – 27 (every two days)	VFA (5mL)	VFA (5mL)	VFA (5mL)
Day 35	TS, TVS and VFA (30mL)	TS, TVS and VFA (30mL)	TS,TVS and VFA (30mL)

9.2.4.2 Samples test methodologies

The methodologies for sampling and testing the physicochemical parameters of the substrate are described as follows (TS, TVS and pH has been descried in Chapter 8 and are not repeated here):

The volume and composition of biogas

As indicated in Section 9.2.4.1, biogas collection was carried out every two days at the same time from each unit of PT2, PT3, C1n, C2n and C3n.

The total biogas volume of pilot plan (SI) was measured by adding all the gas collected from PT2 and PT3. The total biogas volume for C1, C2 and C3 use average amounts collected from of C1n, C2n and C3n (n=a, b, c), respectively.

Due to the gas volume exceeding the capacity of the biogas collector, in this part of experiment, two 3 L gas bags were employed for gas collection from the pilot plant. The volume of biogas is measured by a 1.5 L Super Syringe (HAMC86313, MODEL S1500 TLL SYRINGE, USA) and analysed for methane and carbon dioxide content using a Biogas 5000 gas analyser (Gas Geotech). The process is illustrated in Figure 9.6.

Due to the unavailability of The Automated Methane Potential Test System (AMPTS) II (Jingura and Kamusoko, 2017), this experiment could not employ automatic (real-time) measurements for the recording and reporting of the biogas production.

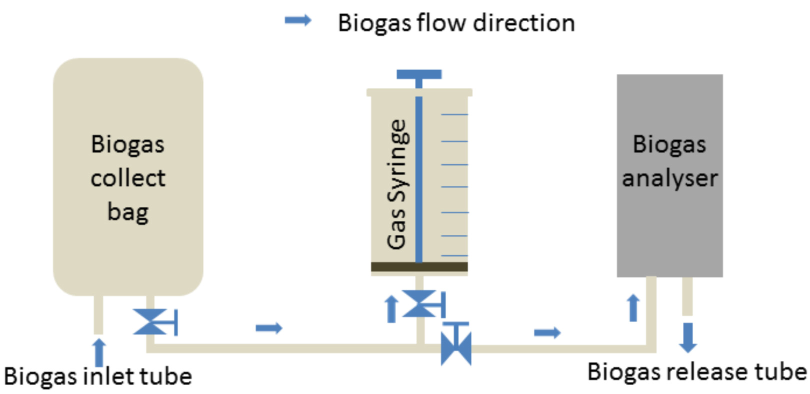


Figure 9.6 The biogas monitoring and testing illustration

9.3 Results and discussion

9.3.1 Pilot plant

9.3.1.1 Run 4

The Figures 9.7 (for data details, see Appendices 9.1 - Tables 9.1.1 and 9.1.2) shows the gas and total VFA concentrations for PT2 and PT3 during R4.

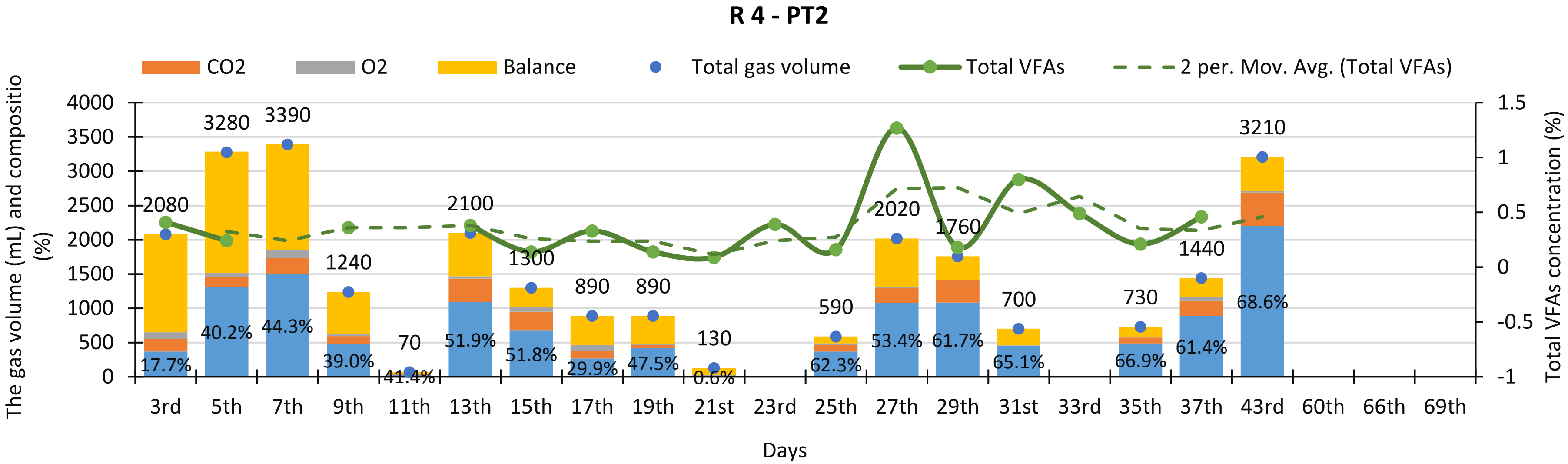
For PT2 in R4, there were three incidents during the run. Firstly, the stirring motor broke down on Day 7 requiring the digestion tank to be opened for repairs, this took place from Day 9 to 11, with resealing taking place on Day 11. On another occasion, the gas outlet tube was found to be inadvertently closed from Day 21 to 23 and Day 31 to 33. During these periods there was no gas generated on these days manifested by a decline in gas volume and CH_4 composition - that subsequently recovered. These incidents also caused the VFA concentration to fluctuate on these occasions as shown in Figure 9.7 (upper). After Day 43 gas production ceased in PT2. On Day 43 the gas volume was 3210 mL, and the CH_4 composition was 68.6%.

For PT3, however, after progressively increasing from Days 27 to 43, the gas volume and CH_4 composition continued to increase to 4575 mL and 82.6%, respectively. The fluctuation of VFAs observed in PT2 continued in PT3, Figure 9.7 (lower).

9.3.1.2 Run 5

Figure 9.8 (for data details, see Appendices 9.2 – Tables 9.2.1 and 9.2.2) shows the gas and total VFA concentration for PT2 and PT3 during R5.

For PT2, before Day 11, the gas volume and CH_4 composition rose suddenly with the CH_4 composition rising to 75.4% on Day 11. However, several incidents occurred here due to air infiltration from the alkaline solution dosing and substrate circulation pump sections. Thus the O_2 composition rose from 5% to 19% (Day 17), 16.6% (Day 19), 20% (Day 21), 12.5% (Day 23) and 20.8% (Day 35) respectively. The raised O_2 poisoned the methanogens causing both the gas volume and the CH_4 composition to drop to near zero, Figure 9.8 (upper).



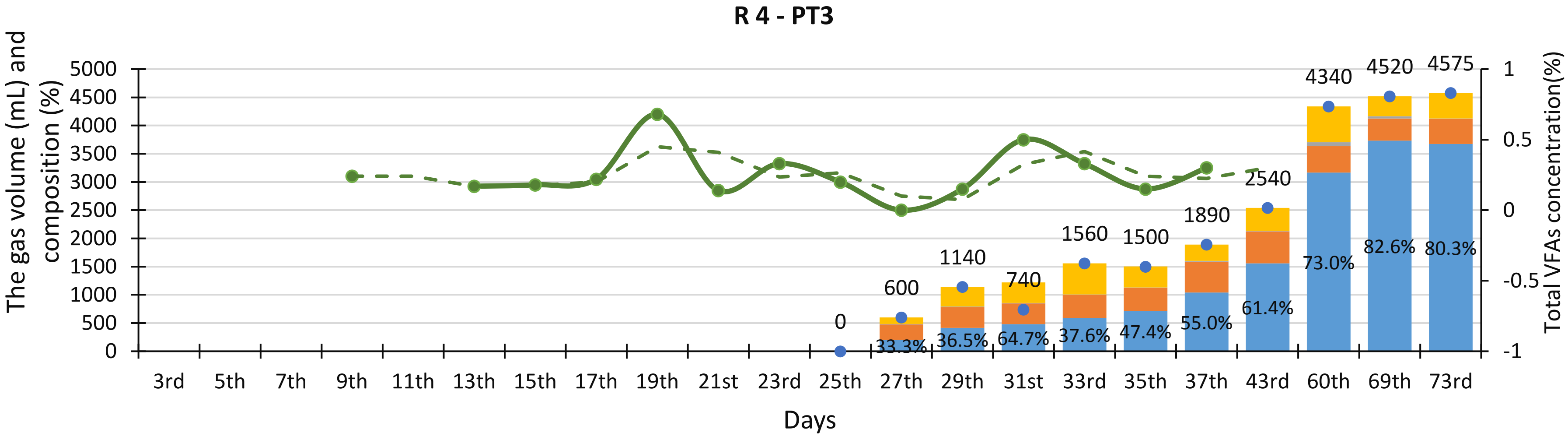


Figure 9.7 The gas volume (mL) and composition (%) and relevant VFAs concentration (%) for R4 for PT2 (upper) and PT3 (lower). Notes: 2 per. Mov. Avg. means the average of the first two data points is used as the first point in the moving average trendline

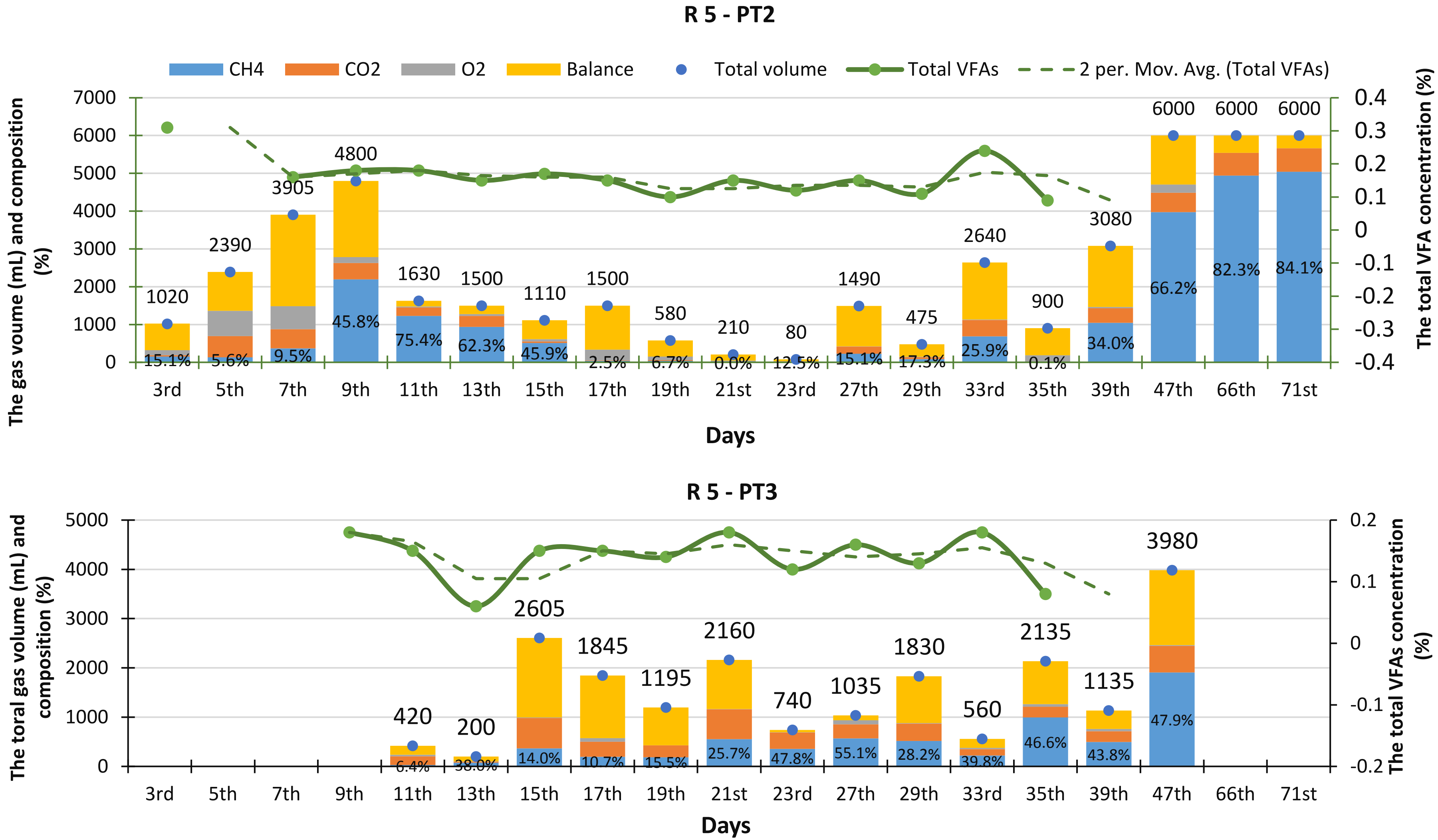


Figure 9.8 The gas volume (mL) and composition (%) and relevant VFAs concentration (%) for R5 for PT2 (upper) and PT3 (lower)

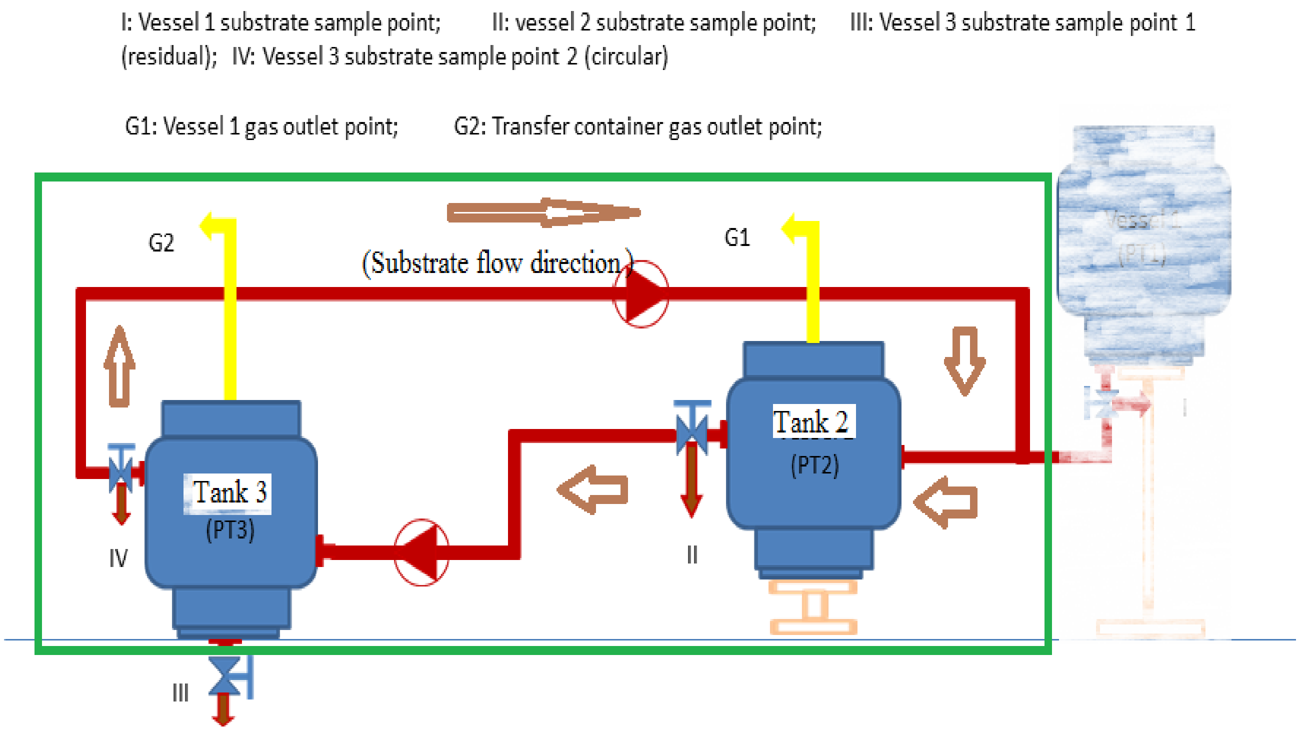


Figure 9.9 The substrate circulation path schematic (circular inside green line) between PT2 and PT3 for R5

To mitigate against the above O_2 infiltration, from Day 27, the substrate was subsequently cycled between PT2 and PT3, Figure 9.9. This was reflected in a reduction in O_2 and an increase in CH_4 after Day 27, Table 9.9.

9.3.1.3 R4 and R5 comparison

Figure 9.10 shows, for PT2 and PT3 combined (i.e. the whole PT), Figure 9.8, the total gas volume (mL) and composition (%) and total VFA concentration (%) for R4 (upper graph) and R5 (lower graph). Both for R4 and R5, for the first 19 Days, there is a production of methane with a maximum percentage composition of up to 61% with a maximum of ~ 2100 mL. They maintain that the relatively low composition and quantity of CH_4 over this period is related (at least in part) to the presence of O_2 in the system, evident from the grey shading bands of the stacked columns of Figure 9.10. In the middle part of the runs, a number of technical incidents occurred, *vide supra*, that interfered with CH_4 production as can be seen in Figure 9.10, Days 20 to 25. However, once these technical problems were addressed and, in particular, the implementation of a transfer of substrate between PT2 and PT3, the gas production resumed and, towards the latter part of both runs, became significantly better with a maximum percentage composition of up to 84%, which is close to the range (87-97%) of natural gas sources[24], and a maximum volume of ~ 6000 mL. This data is summarized in Table 9.9. It can be seen that the quantity and percentage of CH_4 for both R4 and R5 increase upon going from the first time period to the second and, at the same time, the quantity and percentage of the O_2 decreases for both R4 and R5. This strongly supports the strategy of implementing the aforementioned substrate transfer between PT2 and PT3 as a means of reducing the O_2 infiltration and hence increasing the CH_4 yield. In addition, the data in Table 9.9 demonstrates the repeatability of R4 and R5 with respect to CH_4 production given that the quantities for both time periods can reasonably be considered comparable (371 vs 455; 303 vs 453; 41.5 vs 69.6; 26.9 vs 57.3).

Table 9.9 A comparison between the first and final operational periods of the pilot plant with respect to the methane production and oxygen infiltration for R4 and R5. Note that between the two operational periods, the implementation of substrate transfer between PT2 and PT3 was implemented in order to mitigate oxygen infiltration.

Operational time periods		**Gas quantity (mL/day)**		**% of total gas (average)**	
		R4	**R5**	**R4**	**R5**
1st: Day (0 to 27)	CH_4	371	303	41.5	26.9
	O_2	28	88	4.8	7.7
2nd: Day (28 to end)	CH_4	455	453	69.8	57.3
	O_2	6	14	2.2	2.3

The correlation between CH_4 and O_2 may be represented in Figure 9.11. A high correlation may be seen in PT2 since the O_2 levels are higher.

Figure 9.11 shows that when the percentage of O_2 is less than 5, it has a strong correlation with the percentage of CH_4 ($R2>$ 0.8). This indicates that to avoid air leaking is one of major consideration issues in the design and operating processes.

[24] https://www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas

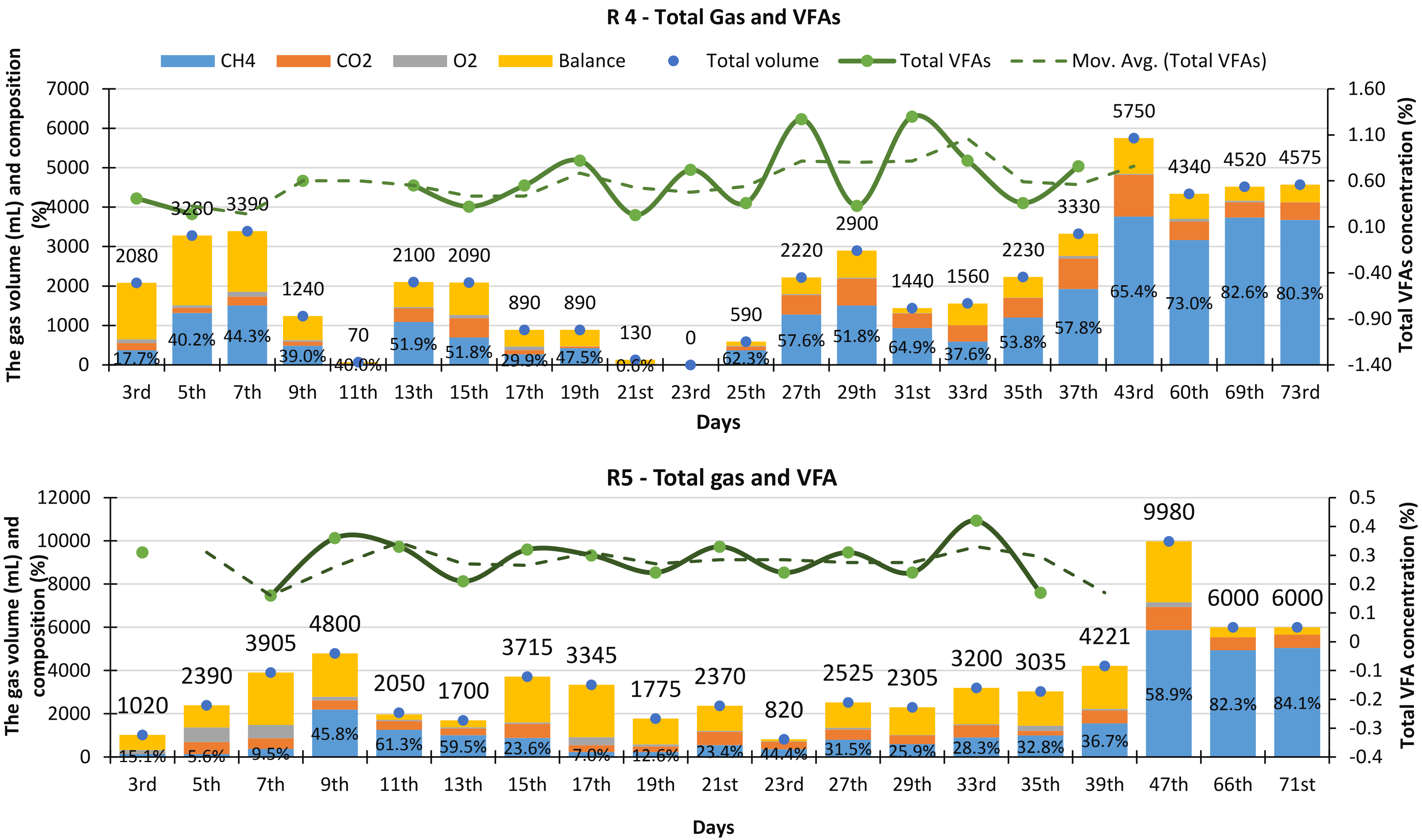


Figure 9.10 The total gas volume (mL), gas composition (%) and total VFAs (%) for the pilot plant. R4 (upper plot) and R5 (lower plot). PT2 and PT3 are combined in both R4 and R5

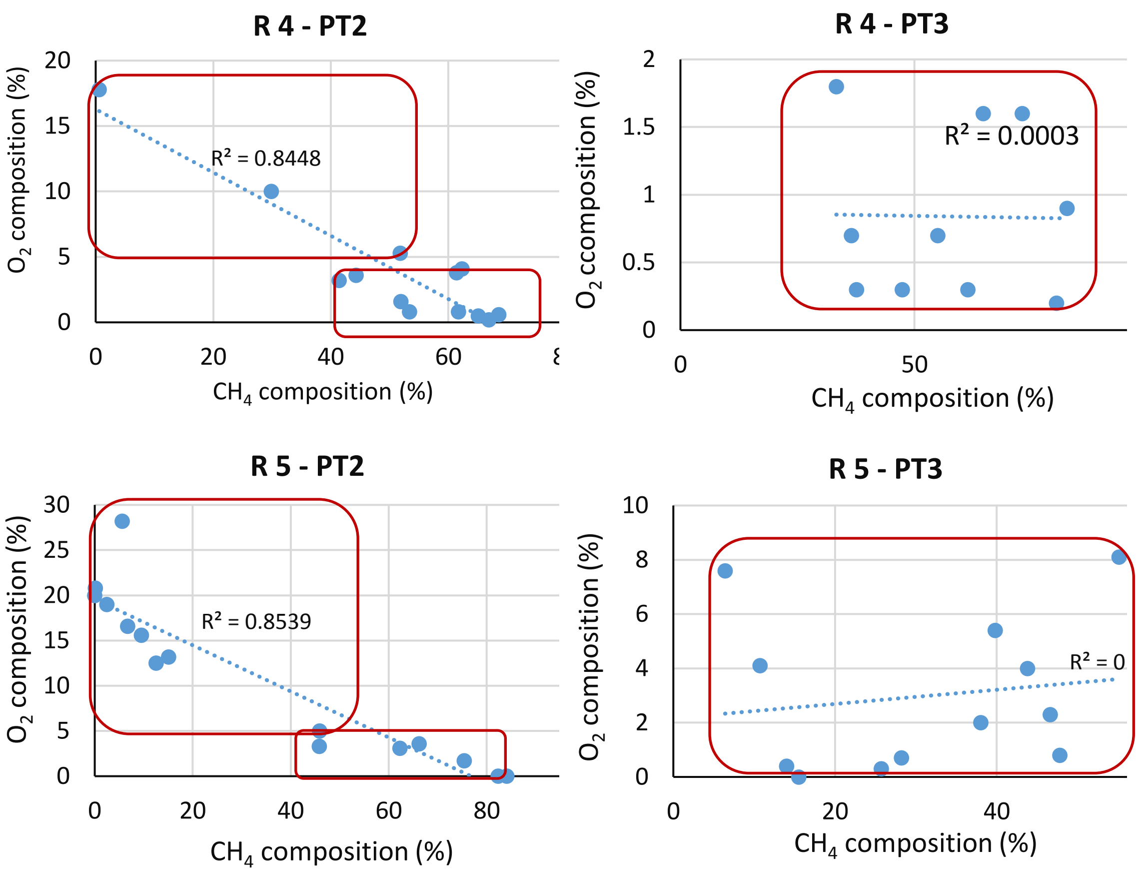
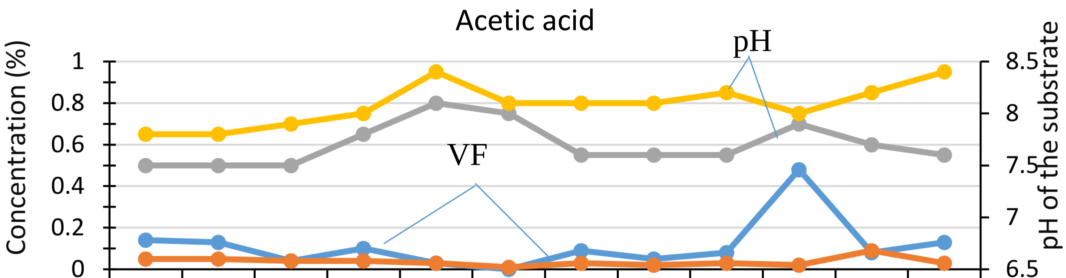


Figure 9.11 Correlation between CH_4 and O_2 for PT2 and PT3

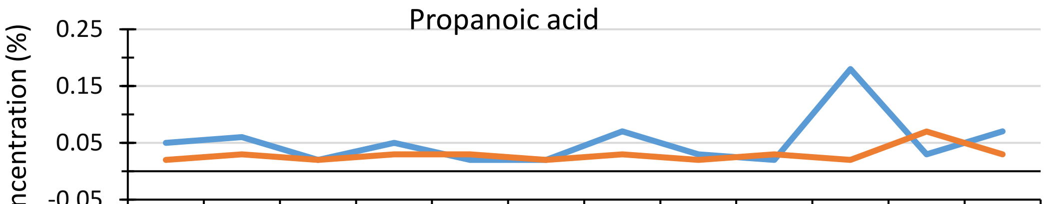
9.3.1.4 Volatile fatty acids

For the four major fatty acids, namely; acetic, propanoic, butyric and valeric acids, the total VFA levels in PT2 and PT3 over R4 and R5 is shown in Figures 9.6, 9.7, respectively, and for PT2 and PT3 combined, in Figure 9.9. Some fluctuations are noted that are attributed to technical interventions and O_2 infiltration. The individual VFA and pH trends are shown in Figures 9.12 to 9.13. Notably there are occasions where the VFAs spike in concentration, both in the case of PT2 and PT3. This can be attributed to technical issues where a build-up of gas pressure within the tank occurred. This is worthwhile noting since the objective of such a bioreactor might be to produce VFAs and this could indicate a possible means of enhancing such production. There is no obvious relationship between the amount of CH_4 produced and the VFA levels.

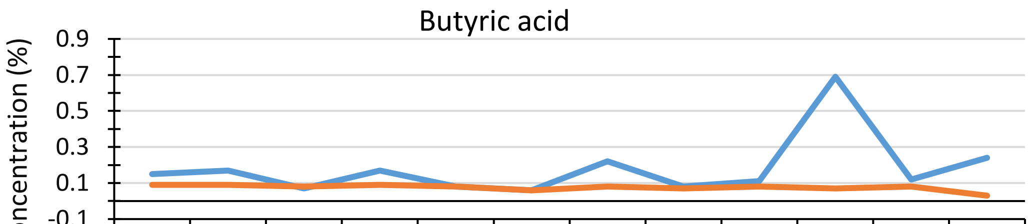


	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.14	0.13	0.04	0.1	0.03	0	0.09	0.05	0.08	0.48	0.08	0.13
Run5	0.05	0.05	0.04	0.04	0.03	0.01	0.03	0.02	0.03	0.02	0.09	0.03
Run4	7.5	7.5	7.5	7.8	8.1	8	7.6	7.6	7.6	7.9	7.7	7.6
Run5	7.8	7.8	7.9	8	8.4	8.1	8.1	8.1	8.2	8	8.2	8.4

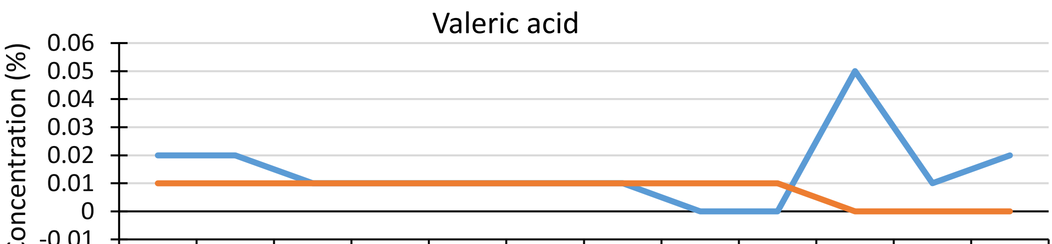
Day of the processes



	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.05	0.06	0.02	0.05	0.02	0.02	0.07	0.03	0.02	0.18	0.03	0.07
Run5	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.07	0.03

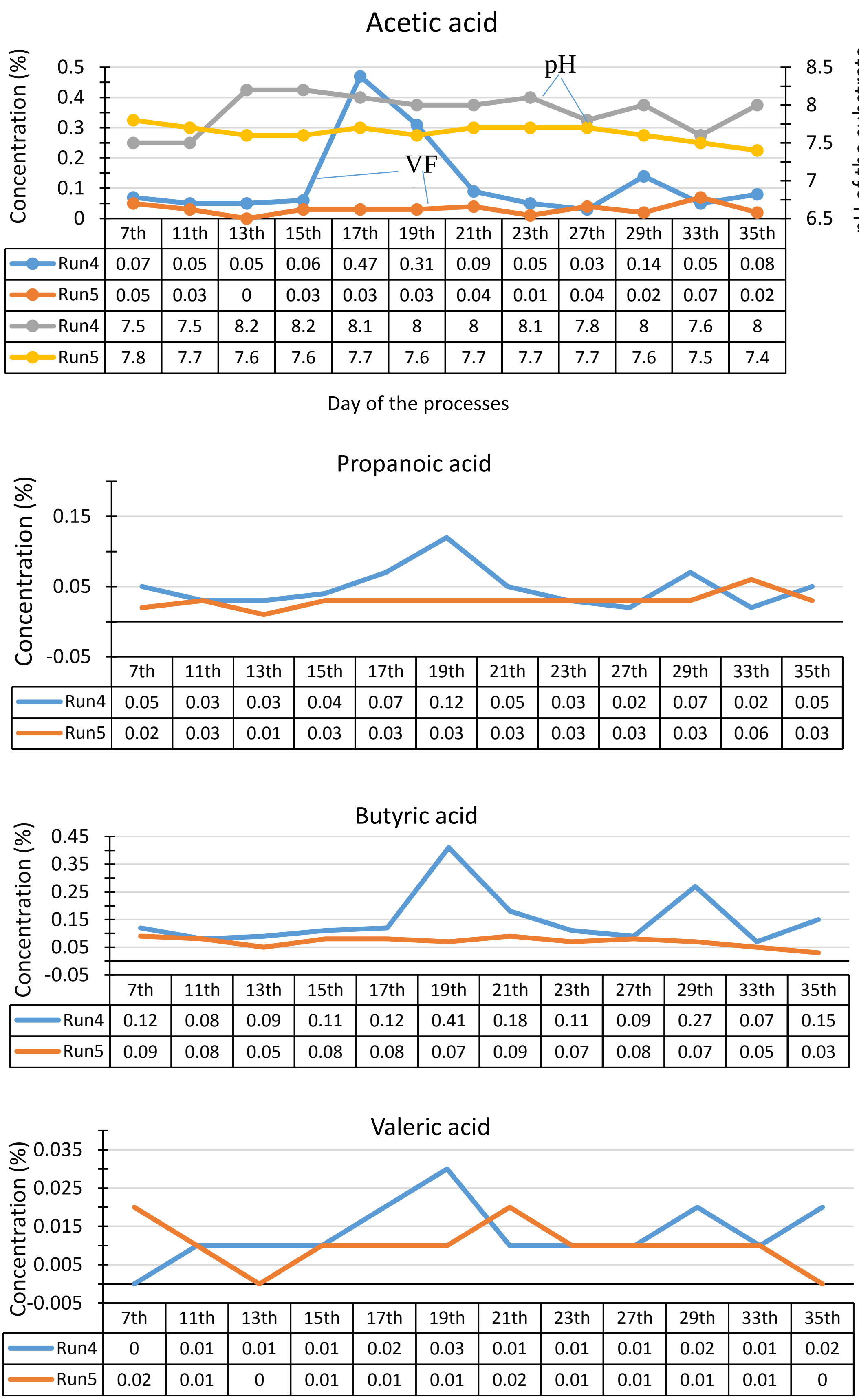


	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.15	0.17	0.07	0.17	0.08	0.06	0.22	0.08	0.11	0.69	0.12	0.24
Run5	0.09	0.09	0.08	0.09	0.08	0.06	0.08	0.07	0.08	0.07	0.08	0.03



	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0	0	0.05	0.01	0.02
Run5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0

Figure 9.12 A levels and pH trend within PT2. The indicated pH trend applies to all the VFAs



Acetic acid

	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.07	0.05	0.05	0.06	0.47	0.31	0.09	0.05	0.03	0.14	0.05	0.08
Run5	0.05	0.03	0	0.03	0.03	0.03	0.04	0.01	0.04	0.02	0.07	0.02
Run4	7.5	7.5	8.2	8.2	8.1	8	8	8.1	7.8	8	7.6	8
Run5	7.8	7.7	7.6	7.6	7.7	7.6	7.7	7.7	7.7	7.6	7.5	7.4

Propanoic acid

	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.05	0.03	0.03	0.04	0.07	0.12	0.05	0.03	0.02	0.07	0.02	0.05
Run5	0.02	0.03	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.03

Butyric acid

	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0.12	0.08	0.09	0.11	0.12	0.41	0.18	0.11	0.09	0.27	0.07	0.15
Run5	0.09	0.08	0.05	0.08	0.08	0.07	0.09	0.07	0.08	0.07	0.05	0.03

Valeric acid

	7th	11th	13th	15th	17th	19th	21th	23th	27th	29th	33th	35th
Run4	0	0.01	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.02
Run5	0.02	0.01	0	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0

Figure 9.13 VFA levels and pH trend within PT3. The indicated pH trend applies to all the VFAs

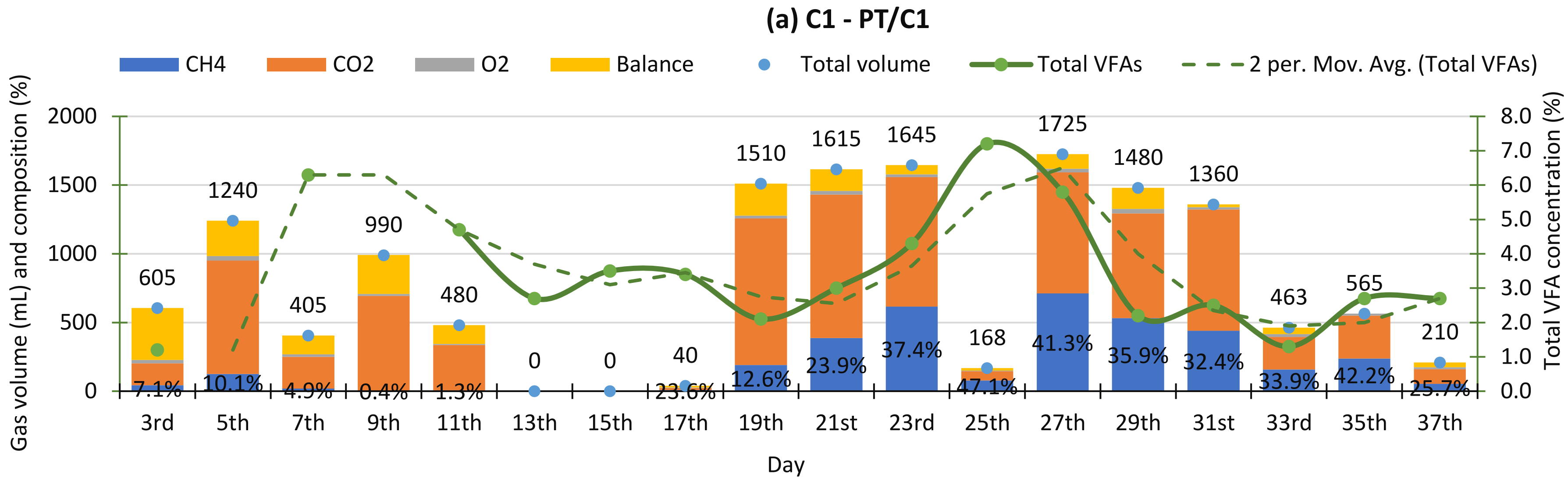
9.3.2 Reference units

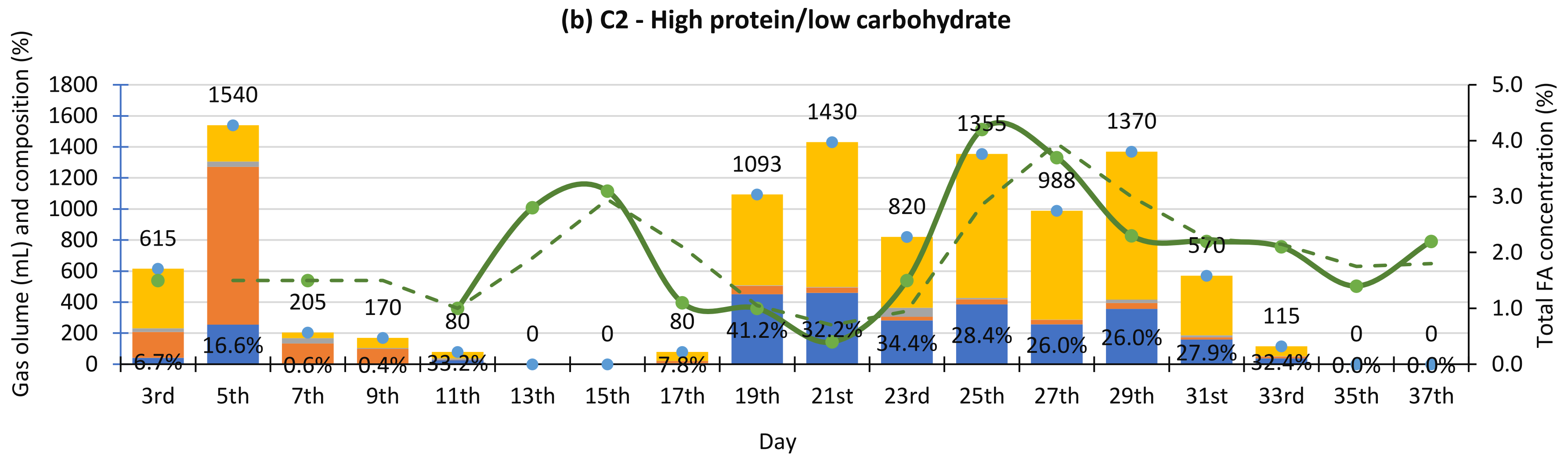
Figure 9.13 shows the gas volumes and composition, and total VFA profiles, for C1, C2 and C3 (data details are provided in Appendix 9.3). The lapse in production from days 13 to 17 for all three units resulted from an inability to provide feedstock for this period due to a breakdown in supply. All three units were halted after 37 Days. The three single tank reference units were each fed with difference food compositions, Tables 9.1, 9.2 and 9.3. Even though CH_4 can be seen to be generated in these units, it is in relatively low yield compared to PT, irrespective of the food waste composition, with a maximum volume of 712 mL and a maximum composition of 53.9%. The O_2 infiltration and pH proved difficult to control in these units. The CH_4 production compared to the O_2 infiltration is shown in Table 9.10. The performance in terms of biogas production is much lower than for the multi-tank PT, Table 9.9. The advantage of a multi-tank setup is that there is more control over the FW digestion process, pH control and O_2 infiltration. The challenge then is to construct a multi-tank system that is as compact as possible – for potential domestic application.

9.4 Conclusions and recommendations

- The experimental set up, as designed, has provided some useful insights into the task of construction and miniaturizing an anaerobic FW digester for domestic use. Notably, it was observed from the operation of the PT system that a methane composition comparable to that of natural gas is possible.

- A major issue that was identified from the operation of the PT set-up was oxygen infiltration. Not unexpectedly, a clear link was established between such infiltration and the methane yield. One strategy that was successfully implemented in order to minimize this, involved transferring substrate between the different anaerobic tanks of the PT. Obviously, this is not be possible for a one tank system such as the reference units - and the actual methane yield from these reference units was observed to be significantly lower than for the multi tank system.


(a) C1 - PT/C1
CH4
CO2
O2
Balance
Total volume
Total VFAs
2 per. Mov. Avg. (Total VFAs)
Gas volume (mL) and composition (%)
Total VFA concentration (%)
Day
3rd
5th
7th
9th
11th
13th
15th
17th
19th
21st
23rd
25th
27th
29th
31st
33rd
35th
37th
605
1240
405
990
480
0
0
40
1510
1615
1645
168
1725
1480
1360
463
565
210
7.1%
10.1%
4.9%
0.4%
1.3%
23.6%
12.6%
23.9%
37.4%
47.1%
41.3%
35.9%
32.4%
33.9%
42.2%
25.7%


(b) C2 - High protein/low carbohydrate
Gas olume (mL) and composition (%)
Total FA concentration (%)
Day
3rd
5th
7th
9th
11th
13th
15th
17th
19th
21st
23rd
25th
27th
29th
31st
33rd
35th
37th
615
1540
205
170
80
0
0
80
1093
1430
820
1355
988
1370
570
115
0
0
6.7%
16.6%
0.6%
0.4%
33.2%
7.8%
41.2%
32.2%
34.4%
28.4%
26.0%
26.0%
27.9%
32.4%
0.0%
0.0%

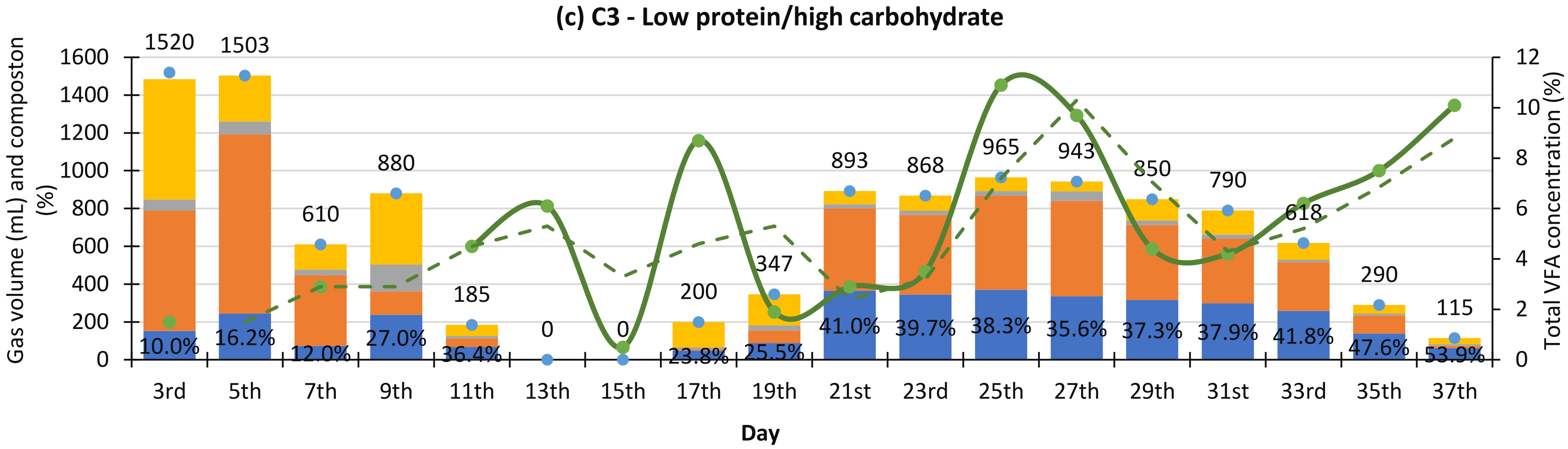


Figure 9.14 The total gas volume (mL) and composition (%) and total VFAs concentration (%) for reference units (a) C1, (b) C2 and (c) C3.

Table 9.10 A comparison between the first and final operational periods of three reference units with respect to the methane production and oxygen infiltration for R4. The average % does not included the days of without gas generation

Operational time periods		Gas quantity (mL/day)			% of total gas (average)		
		C1	**C2**	**C3**	**C1**	**C2**	**C3**
1st: Day (0 to 17)	CH_4	16	26	63	5.5	12.3	16.8
	O_2	8	8	25	2.7	4.0	6.6
2nd : Day (18 to end)	CH_4	170	149	129	31.7	30.8	38.6
	O_2	10	7	11	1.3	0.0	2.0

- Other strategies for the minimization of oxygen infiltration include increasing the concentration of the NaOH, added for pH control, so that a lower volume could be introduced; and ensuring that the PT remains as air-sealed as possible throughout the run. The latter requires the equipment to be as robust as possible so that technical intervention can be avoided. A working prototype for domestic use would necessarily have to take this into account.

- A comparison between the PT and C experiments demonstrate the advantages of maintaining a high level of control over the digestion process, including mixing and pH control.

- There is no obvious relationship between the amount of CH_4 produced and the VFA levels. Generally, there was a steady production of VFAs and, on occasions, a significant spike in production was observed. This was attributed to the occasional technical problem that allowed a build-up of gas pressure within the tank. This is worthwhile noting, since the objective of such a bioreactor might be to produce VFAs and this could indicate a possible means of enhancing such production. This has not been further explored within this study.

- Three FW compositions result in similar VFA profiles, but the different FW compositions do affect the relative compositions of the gases emitted. For example, C1 has the highest CH_4 production rate (98 mL/day) with a CH_4 composition of 21.1%, whereas C2 has the lowest CH_4 production rate (89 mL/day) with a CH_4 composition 29.1%. C1 and C3 have the highest CO_2 composition and C2 has the highest composition of other gases such as H_2S. These results are due the higher C content of C1 and C3 and the higher protein content of C2. This argues for a diversity of foodstuff in the feedstock for maintaining the balance and stability of the fermentation/digestion environment.

- Due to time and equipment constraints, it was not possible to employ the BMP method (see Chapter 6, page) in these studies which could provide an alternative or complimentary method for establishing the baseline performance data of the AD process (Esposito et al., 2012, B. Moody et al., 2011, Sell et al., 2011, Speece, 1983, Schievano et al., 2008). This is an obvious direction for further research.

9.5 References

B. Moody, L, T. Burns, R, Bishop, G, T. Sell, S & Spajic, R 2011, 'Using Biochemical Methane Potential Assays to Aid in Co-substrate Selection for Co-digestion', *Applied Engineering in Agriculture*, vol. 27, no. 3, pp. 433-9.

Esposito, G, Frunzo, L, Liotta, F, Panico, A & Pirozzi, F 2012, 'Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates ', *The Open Environmental Engineering Journal*, vol. 5, no. 1-8, p. 8.

Jingura, RM & Kamusoko, R 2017, 'Methods for determination of biomethane potential of feedstocks: a review', *Biofuel Research Journal*, vol. 14, no. 2017, p. 14.

Schievano, A, Pognani, M, D'Imporzano, G & Adani, F 2008, 'Predicting anaerobic biogasification potential of ingestates and digestates of a full-scale biogas plant using chemical and biological parameters', *Bioresource Technology*, vol. 99, pp. 8112-7.

Sell, ST, Burns, RT, Moody, LB & Raman, DR 2011, 'Comparison of Methane Production from Bench and Sub Pilot-Scale Anaerobic Digesters', *Applied Engineering in Agriculture*, vol. 27, no. 5, p. 8.

Speece, RE 1983, 'Anaerobic biotechnology for industrial wastewater treatment', *Environmental Science & Technology*, vol. 17, no. 9, pp. 416A-27A.

United States Department of Agriculture, ARS *USDA Food Composition Databases*, 29/07/2018, <https://ndb.nal.usda.gov/ndb/search/list?fgcd=&manu=&lfacet=&count=&max=25&sort=default&qlookup=soy+bean+canned&offset=&format=Full&new=&measureby=&ds=&order=asc&qt=&qp=&qa=&qn=&q=&ing=>.

Zhang, Lanying, Liu, Na & Sun, Libo 2005, ’The biological phase of anaerobic biological treatment of wastewater’, *Modern Environmental Microbiology Technology*, Tsinghua University Press Co., Ltd., p. 222.
(张兰英, 刘娜 & 孙立波 2005, '厌氧生物处理废水的生物相', *现代环境微生物技术*, 清华大学出版社有限公司, p. 222.)

Chapter 10: Overall reflections and suggestions for future research

10.1 Overall reflections

Throughout this thesis, Chapter-specific Results and Discussion, and Conclusions, have been provided. However, it is deemed appropriate to consider some overarching reflections, and comments relating to further research, that are documented here. During the course of this research program, the management and treatment of HFW has attracted increasing attention with the rapid growth of population and urbanization internationally. For example, as of 2008, worldwide the number of people living in cities surpassed those living in rural areas and it has been estimated that by 2050, 6 billion people will be living in cities compared with the 3.5 billion currently(UNEP, 2014). There are no simple solutions to the associated waste management problems, including the issue of food waste management and treatment. This is a pressing global issue that also requires consumption and accommodation design paradigm shifts as well as new waste management technological solutions. The UN reports (United Nations General Assembly, 2016) that roughly one third of all food produced for human consumption each year goes to waste - totalling around 1.3 billion tonnes. Interestingly, food waste is distributed fairly evenly between developing and industrialized nations with 40% of the food waste occurring at the retail and consumer levels (Tagliaferri et al., 2016).

Bans and restrictions on landfill disposal have recently increased because of the environmental impact. In this regard, most emerging FW treatment technologies consider both environmental and socio-economic benefits. Amongst these technologies (see Chapter 2), biogas production from FW is purported to potentially improve local economic capabilities, safeguards jobs in rural communities, increases regional purchasing power, improve living standards and contribute towards economic and social development (Garfí et al., 2016, Mwirigi et al., 2014).

A detailed knowledge of the complexities of HFW and how HFW is managed is critical to addressing this issue. For example, the composition of FW is heterogeneous and varies from place to place. The composition is also determined by whether the waste has been segregated based on source or is from a co-mingled source or separated at a materials recovery facility (Fisgativa et al., 2016). For HFW, it can be conveniently divided into three major groups – protein, carbohydrate and cellulose. Fortunately, FW is readily biodegradable and has a high potential methane yield (Wen et al., 2016), estimated at 367 m^3 of biogas per dry tonne, including approx. 65% methane. Globally, for the year 2008, this represents almost 5% of the total global electrical energy utilization of 20,181 TWh. This would be expected to be even more optimistic today. In addition, where anaerobic digestion technology is applied, food waste would not need be sent to landfill, reducing transportation costs and greenhouse gas emissions (Curry and Pillay, 2012).

Life cycle assessment (LCA) is one of the most developed and widely used environmental methodologies for comparing alternative processes or services. It systematically analyses the entire life cycle of goods and services from raw material extraction to the product final disposal, including manufacturing, transport, use, re use, maintenance and recycling, i.e. all flows to and from nature are assessed under a ‘cradle to grave’ perspective. It helps to determine the ‘‘hot spots’’ in the system, that are those activities that have the most significant environmental impact and should be improved as the first priority, thus enabling identification of more environmentally sustainable options. LCA in relation to FW has concluded that AD is the preferred environmental treatment technology focussing on renewable methane production. Furthermore, the projection of Global Warming Potential (GWP) for such processes up until 2035 accounts for future energy scenarios and contributes towards achieving a final goal of closing the food production life cycle (Wang et al., 2017).

However, AD has yet to be significantly introduced into the urban environment. Thus, if the FW produced in the cities was to be source-separated from recyclable materials and digested on-site in small-scale anaerobic reactors, it could provide an important solution to growing FW disposal problems while simultaneously reducing external energy requirements and greenhouse gas emissions. Also, the liquid and solid digestate could then be used as nutrient-rich fertilizers for local grounds and greenhouses. Developing and implementing such anaerobic digestion systems in the urban environment presents a number of unique challenges due to technological and design issues, including the explosive nature of the gases involved (e.g. CH_4 and H_2) and the paradigm shift involved with encouraging citizen waste handling and management inside of city and urban dwelling.

This project has examined both the paradigm (via survey methodology) and the technical issues (via pilot plant construction and testing). For example, in relation to the technical issues, an efficient on-site, small-scale AD system has its own unique considerations that have been addressed herein.

Some further reflections and recommendation for further research from this project are listed below:

- On-site, miniaturized AD technology, suitable for household installation, needs to be further developed and implemented. This will contribute to reducing the environmental impact and will also have economic and social benefits. More specifically, this particular technology will reduce landfill disposal, supplement household gas, encourage composting and reduce the costs of waste collection and disposal. It will also contribute to achieving "zero waste" within a Micro Circular Economic (MCE) framework (Figure 2.16).

- The survey methodology and subsequent results targeting both Council management employees and also residents representing three geographical regions and three major dwelling types, provides critical information that will guide the further development of the above technology.

- Notably, people surveyed across all dwelling types and geographical locations show an encouraging willingness to separate HFW from other waste (> 90%) based on the availability of new environmentally friendly technology and appropriate HFW management Council regulations. Approx. 50% of responses are receptive to using on-site technology to treat HFW and generate biogas, especially for high-rise dwellings.

- Much has been learned for the design, construction and operation of a small AD pilot plant (PT) as has been described within this thesis. This has taken into consideration the complex biochemical characteristics of FW and the special survival and growth environment requirements of methanogens. Factors that contribute to the efficient, high yield production of biogas have been identified in the context of making the technology as small as possible. This provides a platform for the next generation of pilot plant that will lead to a viable commercial product.

- Some of the contributing factors investigated and are suggested for further enquiry, relating to the optimization of CH_4 yield and device miniaturization, include, the role of FW composition as feedstock, the choice of inoculate, improved mixing, increased control over the digestion process, pH control, reduction of O_2 infiltration, temperature control and gas monitoring, collection and storage. There is a requirement for the equipment to be as robust as possible so that technical intervention can be avoided. A working prototype for domestic use would necessarily have to take this into account.

- Generally there was a steady production of VFAs and, on occasions, a significant spike in production was observed. This was attributed to the occasional technical problem that allowed a build-up of gas pressure within the tank. This is worthwhile noting, since the objective of such a bioreactor might be to produce VFAs and this could indicate a possible means of enhancing such production. This has not been further explored within this project. Therefore, a proper understanding of the role of VFAs in the AD process could also be pursued in further research.

10.2 References

Curry, N & Pillay, P 2012, 'Biogas prediction and design of a food waste to energy system for the urban environment', *Renewable Energy*, vol. 41, pp. 200-9.

Fisgativa, H, Tremier, A & Dabert, P 2016, 'Characterizing the variability of food waste quality: A need for efficient valorisation through anaerobic digestion', *Waste Management*, vol. 50, pp. 264-74.

Garfí, M, Martí-Herrero, J, Garwood, A & Ferrer, I 2016, 'Household anaerobic digesters for biogas production in Latin America: A review', *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 599-614.

Mwirigi, J, Balana, BB, Mugisha, J, Walekhwa, P, Melamu, R, Nakami, S & Makenzi, P 2014, 'Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review', *Biomass and Bioenergy*, vol. 70, pp. 17-25.

Tagliaferri, C, Evangelisti, S, Clift, R, Lettieri, P, Chapman, C & Taylor, R 2016, 'Life cycle assessment of conventional and advanced two-stage energy-from-waste technologies for methane production', *Journal of Cleaner Production*, vol. 2016, no. 1-15.

UNEP 2014, *Assessing Global Land Use: balancing consumption with sustainable supply*.

United Nations General Assembly 2016, *Promotion of new and renewable sources of energy*, United Nations.

Wang, P, Wang, H, Qiu, Y, Ren, L & Jiang, B 2017, 'Microbial characteristics in anaerobic digestion process of food waste for methane production–A review', *Bioresource Technology*, no. 2017, p. 8.

Wen, Z, Wang, Y & De Clercq, D 2016, 'What is the true value of food waste? A case study of technology integration in urban food waste treatment in Suzhou City, China', *Journal of Cleaner Production*, vol. 118, pp. 88-96.

Appendices

Appendices (for Chapter 2)

Table 2.1 19 selected references for assessments comparison within difference technologies

Reference	Title	Geography	Waste type	Methodology	Technology	Major finding
Ahamed et al. (2016)	Life cycle assessment of the present and proposed food waste management technologies from environmental and economic impact perspectives	Asian Singapore	FW	Lab-scale experiments, literature, and SimaPro 7.3 libraries	IT, WtE, and AD	-The cost-benefit analysis results show that anaerobic digestion is the best choice if applicable in the local environment. - AD resulted in the lowest resource usage and cost of all the three FW management systems.
Bernstad (2012)	Household food waste management–Evaluations of current status and potential improvements using life-cycle assessment methodology	Worldwide	30-40 % HFW	Investigation LCA	AD, CC, IT and LF	- A 42% increase to a 46% decrease in GHG-emissions in relation to composting and AD.
Bernstad et al. (2016a)	Lifecycle assessment of a system for food waste disposers to tank – A full-scale system evaluation	EU Sweden	HFW	LCA and questionnaires	FWP and AD	- More conventional systems for separate collection and anaerobic digestion of household food waste show that avoided GHG emission could be around 12-34% higher
Bernstad and la Cour Jansen (2011)	A life cycle approach to the management of household food waste – A Swedish full-scale case study	EU	FW	EASEWASTE modelling and experiment	AD, HC and IT	- IT contributes to the largest global warming than AD and HC. -AD with use of biogas and digestate as substitution results in the greatest avoidance of global warming and formation of photochemical ozone compared to HC or IT of food waste.

Bernstad and la Cour Jansen (2012a)	Review of comparative LCAs of food waste management systems – Current status and potential improvements	EU Sweden	FW	Review and comparison of LCAs	AD, CC, IT and LF	- LF in all cases has been ranked as one of the least beneficial alternatives. - AD has the largest benefit.
Chi et al. (2015)	Life cycle assessment of municipal solid waste source-separated collection and integrated waste management systems in Hangzhou, China	China	MSW	Case study	AD, CC, IT and LF with Source-separated collection	- FW's bio-logical technique is essential, which AD is preferable to composting, - IT is environmental advantage than LF, - A total 30, 18, 28 and 29 % of global warming, acidification, nutrient enrichment and photochemical ozone formation has been saved after source separation, respectively, - Material recycling is the main reason for the environmental saving.
Chiu et al. (2015)	Life cycle assessment of waste treatment strategy for sewage sludge and food waste in Macau: perspectives on environmental and energy production performance	Asian Macau	HFW+ Sewage	LCA using SimaPro 7.2.4 software and ReCiPe version 1.04	AD and IT	- AD improves the performance in human health, ecosystems, and energy production by 36, 13, and 61 %, respectively, compared with IT
Dou (2015)	Food waste generation and its recycling recovery: China's governance mode and its assessment	China	FW	Examines and comparison	AD, CC, LF and IT	- AD has smaller land coverage and the smallest recontamination but with medium resource and energy recovery rate, - CC has both medium land coverage and recontamination, with high resource recovery but energy consumption, - IT has low land coverage with highest energy recovery but has the highest investment and operating cost, and 0 resource recovery rate, - LF has the highest land coverage and recontamination, and same time without any resources and energy recovery.
Hill (2010)	Life cycle assessment of municipal waste management: improving on the waste hierarchy	EU Denmark	HFW	Theoretical and Empirical Research within LCA	AD, IT	- IT scenarios still showed a greater environmental benefit than the biogas scenarios. The main reason for this is that the biogas plant depicted in this LCA is fictitious,

						while the IT is already in place and operating. However, the sensitivity analysis shows that if the best case technologies for the biogas scenario are assumed, then AD may in fact be preferable to IT, particularly from a global warming point of view.
Khoo et al. (2010)	Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective	Asian Singapore	FW	Investigation from LCA	AD, CC, HC and IT	- HC system is more environmentally favourable than IT, but less ideal compared to the AD, - AD combined with composting has the least impacts in global warming for the recycling of FW.
Koroneos and Nanaki (2012)	Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective	EU Greece	FW + paper	LCA take into account with social and economic effects.	AD and LF	- AD of FW is preferable compared to LF, due to the energy recovery, the reducing of corresponding amounts of air emissions and non-renewable resource used are considered as avoided environmental impacts.
Levis et al. (2010)	Assessment of the state of food waste treatment in the United States and Canada'	USA and Canada	FW	Cases study	AD and CC	- CC can also lead to VOC, CH_4, and N_2O emissions, - AD is the most desirable alternative from an environmental perspective because of the production and beneficial use of methane and, after aerobic curing, a soil amendment that is similar to what would be generated by CC, - The cost of AD is in the same range as that of mass burn combustion.
Manfredi et al. (2015)	Improving Sustainability and Circularity of European Food Waste Management with a Life Cycle Approach	EU	HFW	EASTECH modelling in LCC and LCA, and survey	AD, CC, IT and LF	- FW of separation collection can increase more than 70% of MSW recycling rate, - The social impacts of FW treatment / management are mainly in 1) the collection/transport of waste; 2) the activities performed in the waste treatment plant; 3) the

						treatment plant's surrounding; and 4) the wider external context, - AD has negative /the lowest environmental and human toxicity impacts, with medium economic performance, - CC has positive but lower environmental and human toxicity impacts, with second lower cost compare to LF, - IT has negative /lower environmental and human toxicity impacts, but with the highest cost / the lowest economic performance, - LF has the lowest cost but with the highest impacts in environmental and human toxicity.
Nakakubo et al. (2012)	Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery	Asian Japan	HFW + Sewage	Case study	AD and IT	- AD has the lowest GHG emission (up to 80.3%) and the highest P recovery ratio (up to 66.3%) compared to IT.
Righi et al. (2013)	Life Cycle Assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches	EU Italy	Organic MSW	Case study	AD and LF	- Reducing transportation in distances and volumes, and decreasing energy input during process will raise environmental benefits within waste treatment, - AD is the sustainable option.
Takata et al. (2013)	The choice of biological waste treatment method for urban areas in Japan—An environmental perspective	Japan	FW	Interview surveys	AD and CC	- The higher energy consumption will cause the higher GHG emissions within CCs, - AD has generated lower rate in total GHG emissions than composting.
Turner et al. (2016)	Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making	UK	HFW	LCA and Material flow analysis	AD , CC, IT, and LF	- AD has the best performer in total GHG impact, - LF has less GHG impact than IT , - Divide FW from the MSW stream will be the most effective strategy in reducing GHG emissions within waste management, because 10% decreased of organic content in MSW will result a -9.4% variation in GHG.

Zhao and Deng (2014)	Environmental impacts of different food waste resource technologies and the effects of energy mix	Asian HK	HFW	EASEWASTE modelling	AD, CC and LF	- LF has the highest GWP even with energy recovery, - CC has 20-37% less GWP than LF, - AD has the highest environmental benefits within AD, CC and LF, - Composting causes serious acidification and nutrient enrichment because of NH_3 and SO_2 emissions during decomposition.
Zschokke et al. (2012)	Comparing environmental impacts of end-of-life treatments of food waste	USA	FW	Investigation using Eco-indicator 99	AD, CC, IT and LF	- AD has the highest benefits in total Eco-indicator including emission of N_2O, CO_2, CH_4 and NH_3 , - CC is in second and IT is in third positions, - LF has the highest impact in total Eco-indicator 99.

Appendices (for Chapter 4)

4.1: City of Melbourne Council/Contractor Interview Questionnaire sheet

COUNCIL/CONTRACTOR INTERVIEW QUESTIONNAIRE

(Note: Not all questions will be relevant to your council. Please answer as best as you can / your knowledge.)

Section A. About food waste data sources:

Q1. What kind of organic waste data do you have?

We don't collect data on household food waste.

We have data on the amount of garden waste collected through the monthly collection available to residents on call.

Q2. Who collected/collects the data?

Our waste services collection contractor, Citywide.

Q3. How is data relevant to food waste collected?

The data is not relevant to food waste.

Q4. Does such data relate to specific kinds of communities or dwelling types or are they averaged / aggregated? If answer is "Yes", could you please provide the data or source?

Aggregated.

Q5. Is such data publicly available?

No

Q6. Are there any gaps in food waste data for your council? If answer is "Yes", could you please provide the data or source?

Yes – we don't have any data on food waste!

Q7. Are there any figures for the last (say) 15 years and projections for the next (say) 15 years? If answer is "Yes", could you please provide the data or source?

No

Q8. What are the resident densities that relevant to those figures?

N/A

Section B. Food waste management:

Q9. Who is responsible for garbage collection and treatment?

Household waste is collected by our waste services contractor (Citywide) and disposed at the Wyndham City Council landfill in Werribee.

Q10. What kind of collection system is used in your shire?

Bin-based

Q11. How many garbage transporting /sorting stations are there within your shire?

Our garbage is collected and taken to Dynon Road waste and recycling centre (transfer station) before being bulk transported to Werribee.

Q12.What percentage of garbage, after sorting, is sent to landfill in your shire?

Garbage is not sorted.

Q13. What are the costs involved in managing such waste?

Refer annual plan and budget: http://www.melbourne.vic.gov.au/sitecollectiondocuments/annual-plan-budget-2017-18.pdf

Q14. What proportion of the council rates does this constitute?

Refer annual plan and budget:
http://www.melbourne.vic.gov.au/sitecollectiondocuments/annual-plan-budget-2017-18.pdf

Section C. Food waste treatment methods/technology:

Q15. What percentage of food waste is composted with listed treatment methods?

Centralised: No centralised food waste treatment occurs for household food waste.

Home based: We don't have data on how much home-based food waste treatment occurs.

Q16. What percentage of food waste is treated using anaerobic digestion technology in your shire?

Centralised: None

Home based: None

Q17. What are the important issues when choosing a treatment technology?

(Please rank these issues in order of importance.)

N/A

Section D. Questions of relevance to food waste management

Q18. What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?

Our current Waste and Resource Recovery Plan 2015-18 (WRRP) is available here: http://www.melbourne.vic.gov.au/residents/waste-recycling/pages/waste-resource-recovery-plan.aspx

Q19. What are the barrier to the implementation of a "toward zero waste" policy?

Refer 'challenges' listed in the WRRP.

Q20. Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?

There is another part of CoM who deal with research collaborations. If you'd like their details please let me know.

Q21. Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?

Yes (as we have already discussed)

Q22. Would the council be willing to subsidize the participation of residents in project designed to advance the management of household food waste?

We will be developing our own responses to household food waste this year.

THANKYOU FOR TAKING THIS INTERVIEW WITH US:

Would you permit me to follow-up and clarify some of the responses you provided in this survey?

If yes, please provide some of your details below.

Name: Melanie Oke

Organisation:_City of Melbourne

Position: Waste Management Coordinator

Email: _melanie.oke@melbourne.vic.gov.au

Telephone: _03 9658 9951 Mobile: ___________________________________

Preferred way to contact you: _email is usually best

4.2: City of Yarra Council/Contractor Interview Questionnaire sheet

COUNCIL/CONTRACTOR INTERVIEW QUESTIONNAIRE

(Note: Not all questions will be relevant to your council. Please answer as best as you can / your knowledge.)

Section A. About food waste data sources:

Q1. What kind of organic waste data do you have?

% food and green data weight and volume.

Q2. Who collected/collects the data?

Our waste services collection contractor, Citywide.

Q3. How is data relevant to food waste collected?

Yarra Municipal Kerbside waste

Q4. Does such data relate to specific kinds of communities or dwelling types or are they averaged / aggregated? If answer is "Yes", could you please provide the data or source?

Q5. Is such data publicly available?

No

Q6. Are there any gaps in food waste data for your council? If answer is "Yes", could you please provide the data or source?

The food and green waste being created by different sectors of the community eg. C&I and C&D.

Q7. Are there any figures for the last (say) 15 years and projections for the next (say) 15 years? If answer is "Yes", could you please provide the data or source?

No

Q8. What are the resident densities that relevant to those figures?

N/A

Section B. Food waste management:

Q9. Who is responsible for garbage collection and treatment?

Four Seasons

Q10. What kind of collection system is used in your shire?

80L rubbish bin and 120 L recycling bin a week

Q11. How many garbage transporting /sorting stations are there within your shire?

None

Q12.What percentage of garbage, after sorting, is sent to landfill in your shire?

60% by weight.

Q13. What are the costs involved in managing such waste?

Lots

Q14. What proportion of the council rates does this constitute?

Approximately 30%

Section C. Food waste treatment methods/technology:

Q15. What percentage of food waste is composted with listed treatment methods?

Centralised: 0%

Home based: 1% we are doing a trial

Q16. What percentage of food waste is treated using anaerobic digestion technology in your shire?

Centralised: None

Home based: None

Q17. What are the important issues when choosing a treatment technology?

(Please rank these issues in order of importance.)

Tested, doesn't create odour or leakage, is not too fare away

Section D. Questions of relevance to food waste management

Q18. What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?

There is no zero waste policy – it's a less waste more resources policy

Q19. What are the barrier to the implementation of a "toward zero waste" policy?

Q20. Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?

Yes

Q21. Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?

Yes (as we have already discussed)

Q22. Would the council be willing to subsidize the participation of residents in project designed to advance the management of household food waste?

Not sure, depends what for and how much?

THANKYOU FOR TAKING THIS INTERVIEW WITH US:

Would you permit me to follow-up and clarify some of the responses you provided in this survey?

If yes, please provide some of your details below.

Name: ___Lisa Coffa____

Organisation:___City of Yarra____

Position: ___Waste Minimisation and Urban Agriculture Coordinator________________

Email: ___Lisa.coffa@yarracity.vic.gov.au_______________________________________

Telephone: _________________________ Mobile: _0407352739__________

Preferred way to contact you: __email____

4.3: City of Wyndham Council/Contractor Interview Questionnaire sheet

COUNCIL/CONTRACTOR INTERVIEW QUESTIONNAIRE

(Note: Not all questions will be relevant to your council. Please answer as best as you can / your knowledge.)

Section A. About food waste data sources:

Q1. What kind of organic waste data do you have?

Tonnage rates from Compost processor, estimated diversion and CO2 saving from Compost Revolution (provides compost bins and worm farms to residents) and waste audit data

Q2. Who collected/collects the data?

Contractors

Q3. How is data relevant to food waste collected?

Both accept food waste, Compost REvoltion would mostly be food waste

Q4. Does such data relate to specific kinds of communities or dwelling types or are they averaged / aggregated? If answer is "Yes", could you please provide the data or source?

No

Q5. Is such data publicly available?

Some is via Wyndham's State of the Environment Report

Q6. Are there any gaps in food waste data for your council? If answer is "Yes", could you please provide the data or source?

Not that I am aware of.

Q7. Are there any figures for the last (say) 15 years and projections for the next (say) 15 years? If answer is "Yes", could you please provide the data or source?

Not that I am aware of

Q8. What are the resident densities that relevant to those figures?

80,000 dwellings: mixed low, medium and high density

Section B. Food waste management:

Q9. Who is responsible for garbage collection and treatment?

Wyndham City and Waste Contractor JJ Richards

Q10. What kind of collection system is used in your shire?

Side lift trucks providing weekly and fortnightly service

Q11. How many garbage transporting /sorting stations are there within your shire?

One

Q12.What percentage of garbage, after sorting, is sent to landfill in your shire?

100% by weight.

Q13. What are the costs involved in managing such waste?

Multiple millions

Q14. What proportion of the council rates does this constitute?

Cannot disclose

Section C. Food waste treatment methods/technology:

Q15. What percentage of food waste is composted with listed treatment methods?

Centralised: 1% in vessel aerobic composting

Home based: Unsure

Q16. What percentage of food waste is treated using anaerobic digestion technology in your shire?

Centralised: None

Home based: None

Q17. What are the important issues when choosing a treatment technology?

(Please rank these issues in order of importance.)

Cost, accepted feedstock, maintenance, end market of product

Section D. Questions of relevance to food waste management

Q18. What activities have been taken /will be taken by your city in response to the state government's "toward zero waste policy"?

Adopted Waste and Litter Strategy with numerous waste diversion/minimisation targets and a goal to have 90% diversion from Landfill by 2040.
Newly created roles in Waste Strategy and Waste Education

Q19. What are the barrier to the implementation of a "toward zero waste" policy?

Community feedback/support, Councillor support, existing infrastructure, budget constraints

Q20. Are you interested in collaborating with Victoria University's micro "Circular-Economies" in relation to the management of household kitchen-waste recovery?

No

Q21. Are you able assisting us with a survey of council residents in order to understand their food consumption and disposal activities?

Yes (as we have already discussed)

Q22. Would the council be willing to subsidize the participation of residents in project designed to advance the management of household food waste?

We already do – Compost Revolution

THANKYOU FOR TAKING THIS INTERVIEW WITH US:

Would you permit me to follow-up and clarify some of the responses you provided in this survey?

If yes, please provide some of your details below.

Name: __Evan Lockhart____

Organisation:__Wyndham City Council____

Position: __Team Leader Waste Services____

Email: ___evanlockhart@wyndham.vic.gov.au____
_

Telephone: _8734 5488 ext: 2042 ________________Mobile: ____________________________

Preferred way to contact you: __phone____

Appendices (for Chapter 5)

5.1: INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: "Making the Best Use of Household Waste".

This project is being conducted by a student researcher, Ms Meris Zheng, as part of a PhD Study at Victoria University under the supervision of Professor John Orbell from the College of Engineer & Science/Institute for Sustainability & Innovation.

Project explanation

Researchers at Victoria University are interested in the development of household technology that will enable household food waste to be converted into useable energy. To support this research, information is needed from the occupants of different kinds of dwelling on how they currently manage their food waste and their attitudes to various approaches to food waste management or disposal. Such information will assist the researchers to design technology that is "fit for purpose".

What will I be asked to do?

Participants are requested to participate in a short anonymous survey that should take no more than five to ten minutes.

What will I gain from participating?

Participants will have contributed to the advancement of research into ways of reducing and exploiting domestic food waste for the benefit of the environment and the economy.

How will the information I give be used?

The researcher will collate and analyse the information from a large number of participants and draw conclusions about how food waste is managed in different dwelling types and by different kinds of individuals. This will inform the development of the most appropriate technology for the conversion of food waste to useable energy at the household level.

What are the potential risks of participating in this project?

There are no identifiable risks of participating in this project.

How will this project be conducted?

This project is to be conducted by surveying members of the public at community events.

Who is conducting the study?

This is part of a PhD research program conducted by a research student and her academic supervisor from Victoria University.

Chief Investigator: Professor John Orbell, College of Engineering & Science/Institute for Sustainability & Innovation, Victoria University. Email: John.Orbell@vu.edu.au

Student Researcher: Ms Meris Zheng, College of Engineering & Science/Institute for Sustainability & Innovation, Victoria University. Email: meris.zheng@live.vu.edu.au

Any queries about your participation in this project may be directed to the Chief Investigator listed above. If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

V.1/2013 1 of 1

5.2: The streets / blocks information detail of flier delivered

Table 5.2.1 The blocks information of fliers delivered in City of Melbourne

<table>
<tr><th colspan="2">Name of the block</th><th>Address name</th><th>Number of levels</th><th>Number of apartments</th></tr>
<tr><td rowspan="4">Upper West Side complex</td><td>Tower 1</td><td>220 Spencer St.</td><td>45</td><td>700</td></tr>
<tr><td>Tower 2</td><td>639 Lonsdale St.</td><td>48</td><td>584</td></tr>
<tr><td>Tower 3</td><td>33 Rose Lane</td><td>52</td><td>641</td></tr>
<tr><td>Tower 4</td><td>11 Rose Lane</td><td>30</td><td>282</td></tr>
<tr><td colspan="2"></td><td>163 City rd. Southbank</td><td>24</td><td>200</td></tr>
<tr><td colspan="2">Melbourne Tower</td><td>171 City Rd.</td><td>36</td><td>315</td></tr>
<tr><td colspan="2"></td><td>283 City Rd.</td><td>40</td><td>360</td></tr>
<tr><td colspan="2"></td><td>45 Clarke St.</td><td>51</td><td>437</td></tr>
<tr><td colspan="2">City Tower</td><td>183 City Rd.</td><td>36</td><td>303</td></tr>
<tr><td colspan="2">Victoria Tower</td><td>100 Kavanagh St.</td><td>30</td><td>24</td></tr>
<tr><td colspan="2">Epic apartments</td><td>118 Kavanagh St.</td><td>37</td><td>415</td></tr>
<tr><td colspan="2"></td><td>88 Southbank Boulevard</td><td>24</td><td>187</td></tr>
<tr><td colspan="2">The Boyd</td><td>5 Caravel Lane</td><td>22</td><td>172</td></tr>
<tr><td colspan="2">The Palladio</td><td>15 Caravel Lane</td><td>22</td><td>197</td></tr>
<tr><td colspan="2">The Arkley</td><td>16 – 32 Rakaia Way</td><td>22</td><td>176</td></tr>
</table>

Table 5.2.2 The information of fliers delivered in selected areas in City of Yarra

Suburb	Household number in 2016	Delivered number of fliers	Proportion for the households
Fitzroy, Fitzroy N	10,085 (4,671+5,414)	1,011	10.02 %
Carlton N, Princes Hill	3,892	230	5.91 %
Central Richmond	6,478	534 (160 +374)	8.24 %

Table 5.2.3 The streets detail information of fliers delivered in City of Yarra

Date	Suburb	Street name	Street number	Building name	Number of apartments in block	Number of survey forms delivered
11/09/ 2018	Fitzroy	Argyle St.	160-164		38	38
			192		10	10
		Charles St.	132		4	4
			174-196		54	44
		Condell St.	60		9	9
		George St	23	Victoria garden	40	40
			58 – 62		11	11
			65		18	18
			98		12	12
			111		3	3
			144		10	10
			186-188	Margaret flats	4	4
			210		6	6
		Gertrude St	166		26	26
		Gors St.	269		6	6
			366-390		8	8
		Kerr St	183		60	60
		Napier St	58		22	22
			443		8	8
			497-530		8	8
		St. David St	1		54	54
			5		30	30
			30		3	3
			40		22	22
		Young St	113– 117		10	10
			212-204		5	5
			237		2	2
			300		100	100
13/09/ 2018	Fitzroy	Fitzroy St.	161		4	4
			175	Birchgrove place	12	12
			176		9	9
			207		4	4
13/09	Fitzroy	Gertrude St	110		7	7
13/09	Fitzroy	Greeves St	84		12	12
13/09	Fitzroy	Hanover	3 - 25		36	36
			27 - 33		11	11
			40		6	6
			41		12	12
			47		12	12

Date	Suburb	Street name	Street number	Building name	Number of apartments in block	Number of survey forms delivered
13/09/2018	Fitzroy	King William St	2		21	21
			29		15	15
			32		21	21
			40		21	21
			50		12	12
		Napier St	8		8	8
			41		24	24
			64 - 68		12	12
		Moor St	40		15	15
			45		14	14
			50		5	5
			108-110		18	18
		Palmer St	21		8	8
			45		4	4
			50		11	11
			56	Carrington	12	12
			74	Summer house	10	10
		Rose St	25 - 33	Rose apartments	20	20
			42		6	6
			45		23	23
			71 - 73		4	4
			88		8	8
		Young St	52 - 54		12	12
			59		10	10
					Subtotal	1011
17/09/2018	Central Richmond	Church St	343		32	32
			361		4	4
			366		30	30
			368		6	6
			370		8	8
			372		15	15
			376		5	5
		McGrath CT	4			12
			5			12
			7			20
			10			6
		Bridge Rd	2			10
17/09/2018	N. Richmond	Highett St	9	Jaques	9	9

Date	Suburb	Street name	Street number	Building name	Number of apartments in block	Number of survey forms delivered
22/09/2018	Central Richmond	Doccker St	2		18	18
		Hoddle St	199	Walacon	12	12
			201		12	12
			203	Yarra view	11	11
		Lennox St	168		5	2
			176		16	16
			180		12	12
			190	Edgewood	20	20
			196	Goodwood lodge	6	6
			197		12	12
			197	Kent & Devon	16	16
			200	Hill court	12	12
			201		15	15
			215		10	10
			218		14	13
			219	Rowena gardens	4	4
			239		16	15
			249		6	6
			257 - 259	Lennex place	6	4
			263		12	11
			267-269		8	8
			271-273	Lexington	8	8
		Richmond CT	63		9	9
			65 -67		12	12
			71		8	8
			88 - 90		12	12
		Sherwood St	2		12	11
			15		12	10
			27		12	12
		Tanner St	11		15	15
			30		26	26
			60		6	4
		Waltham St	33		14	4
					Subtotal	383

<table>
<tr><th>Date</th><th>Suburb</th><th>Street name</th><th>Street number</th><th>Building name</th><th>Number of apartments in block</th><th>Number of survey forms delivered</th></tr>
<tr><td rowspan="4">11/09/18</td><td rowspan="4">Princes Hill</td><td>Wilson St</td><td>109</td><td>Princes Lodge</td><td>15</td><td>15</td></tr>
<tr><td>Arnold St</td><td>311</td><td>-</td><td>7</td><td>7</td></tr>
<tr><td>Wilson St</td><td>106</td><td>-</td><td>6</td><td>6</td></tr>
<tr><td>McIlwraith St</td><td>19</td><td>-</td><td>18</td><td>18</td></tr>
<tr><td rowspan="5">13/09/18</td><td rowspan="5">Carlton N</td><td rowspan="5">Park St</td><td>671</td><td>-</td><td>24</td><td>24</td></tr>
<tr><td>673</td><td>-</td><td>6</td><td>6</td></tr>
<tr><td>675</td><td>-</td><td>9</td><td>9</td></tr>
<tr><td>677</td><td>Brompton</td><td>24</td><td>24</td></tr>
<tr><td>695</td><td>Park View</td><td>16</td><td>16</td></tr>
<tr><td>13/09/18</td><td>Princes Hill</td><td>Garton St</td><td>12</td><td>Carlton Plaza</td><td>21</td><td>6</td></tr>
<tr><td rowspan="2">14/09/18</td><td rowspan="2">Princes Hill</td><td rowspan="2">Garton St</td><td>12</td><td>Carlton Plaza</td><td>21</td><td>8</td></tr>
<tr><td>26</td><td>-</td><td>21</td><td>21</td></tr>
<tr><td rowspan="2">27/09/18</td><td rowspan="2">Carlton</td><td rowspan="2">Cardiagan St</td><td>404</td><td></td><td>20</td><td>20</td></tr>
<tr><td>495</td><td></td><td>50+</td><td>50</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Subtotal</td><td>230</td></tr>
<tr><td>13/09/18</td><td>Brunswick</td><td>Sydney Rd</td><td>6</td><td>-</td><td>12</td><td>12</td></tr>
<tr><td>14/09/18</td><td>Parkville</td><td>Royal Parade</td><td>445</td><td></td><td>46</td><td>46</td></tr>
<tr><td rowspan="2">18/09/18</td><td rowspan="2">Brunswick</td><td>Lygon St</td><td>1-9</td><td>-</td><td>140</td><td>110</td></tr>
<tr><td>Brunswick Rd</td><td>70 - 74</td><td></td><td>24</td><td>12</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Subtotal</td><td>180</td></tr>
</table>

5.3: Motivation for segregation of HFW from other waste in detached dwellings.

Table 5.3.1 Motivation for segregation of HFW from other waste in detached dwellings.

Total	1–	2–	3–	4–	5–	6–	SCORE–
Council regulation							**2.2**
Percentage	6.01%	9.84%	12.02%	19.13%	36.07%	15.30%	
No. of responses	11	18	22	35	66	28	
Peer pressure							**1.2**
Percentage	7.10%	3.28%	1.09%	4.37%	25.14%	57.38%	
No. of responses	13	6	2	8	46	105	
Economic benefit							**2.8**
Percentage	10.38%	11.48%	20.77%	36.07%	12.02%	7.65%	
No. of responses	19	21	38	66	22	14	
Availability of separating and disposal technology							**2.8**
Percentage	36.61%	20.22%	19.13%	10.38%	8.20%	4.92%	
No. of responses	67	37	35	19	15	9	
Environmental reasons							**4.5**
Percentage	29.51%	30.06%	14.21%	8.74%	9.29%	6.56%	
No. of responses	54	55	26	16	17	12	
Cleanliness/hygiene							**3**
Percentage	9.84%	23.50%	31.15%	19.67%	8.20%	6.01%	
No. of responses	18	43	57	36	15	11	

Table 5.3.2 Motivation for segregation of HFW from other waste in semidetached/low-rise dwellings.

Total	1–	2–	3–	4–	5–	6–	SCORE–
Council regulation							**2.6**
Percentage	5.33%	9.33%	9.78%	17.33%	38.67%	11.56%	
No. of responses	12	21	22	39	87	26	
Peer pressure							**1.5**
Percentage	2.22%	1.33%	4.00%	6.22%	15.11%	61.78%	
No. of responses	5	3	9	14	34	139	
Economic benefit							**3.4**
Percentage	11.11%	14.22%	22.22%	26.67%	14.22%	5.33%	
No. of responses	25	32	50	60	32	12	
Availability of separating and disposal technology							**4.2**
Percentage	29.33%	24.89%	16.89%	13.33%	6.67%	1.78%	
No. of responses	66	56	38	30	15	4	
Environmental reasons							**4.6**
Percentage	44.44%	21.78%	12.44%	8.44%	4.44%	3.11%	
No. of responses	100	49	28	19	10	7	
Cleanliness/hygiene							**3.5**
Percentage	8.44%	20.44%	25.78%	19.11%	11.56%	11.11%	
No. of responses	19	46	58	43	26	25	

Table 5.3.3 Motivation for segregation of HFW from other waste in high-rise dwellings.

Total	1–	2–	3–	4–	5–	6–	SCORE–
Council regulation							**2.8**
Percentage	6.01%	9.84%	12.02%	19.13%	36.07%	15.30%	
No. of responses	11	18	22	35	66	28	
Peer pressure							**1.8**
Percentage	7.10%	3.28%	1.09%	4.37%	25.14%	57.38%	
No. of responses	13	6	2	8	46	105	
Economic benefit							**3.4**
Percentage	10.38%	11.48%	20.77%	36.07%	12.02%	7.65%	
No. of responses	19	21	38	66	22	14	
Availability of separating and disposal technology							**4.5**
Percentage	36.61%	20.22%	19.13%	10.38%	8.20%	4.92%	
No. of responses	67	37	35	19	15	9	
Environmental reasons							
Percentage	29.51%	30.06%	14.21%	8.74%	9.29%	6.56%	**4.4**
No. of responses	54	55	26	16	17	12	
Cleanliness/hygiene							**3.8**
Percentage	9.84%	23.50%	31.15%	19.67%	8.20%	6.01%	
No. of responses	9.84%	23.50%	31.15%	19.67%	8.20%	6.01%	

5.4 Average responses to Q16, Q17 and Q18 respectively

Table 5.4.1 Average responses to Q16, Q17 and Q18 respectively left to right for detached dwellings.

Q 16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	9	2	15	48	265	339	
%	2.62%	0.58%	4.40%	13.99%	77.26%		
Weight	0.03	0.01	0.13	0.56	3.86		4.6

Q 17 Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	4	10	30	64	230	338	
%	1.17%	2.90%	8.75%	18.66%	67.06%		
Weight	0.01	0.06	0.26	0.75	3.35		4.3

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	34	32	118	64	90	338	
%	9.91	9.33	34.40	18.66	26.24		
Weight	0.1	0.19	1.03	0.75	1.31		3.4

Table 5.4.2 Average responses to (a) Q16, (b) Q17 and (c) Q18 respectively left to right for semi-detached/ Low-rise dwellings.

Q 16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total–	Weighted average
Total	1	1	14	39	169	224	
%	0.40	0.40	6.22	17.33	75.11		
Weight	0.004	0.008	0.19	0.69	3.76		4.7

Q 17 Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	0	1	17	54	152	224	
%	0.00	0.40	7.56	24.00	67.56		
Weight	0	0.008	0.23	0.96	3.38		4.6

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	30	32	81	43	28	224	
%	13.33	14.22	36.00	19.11	12.44		
Weight	0.13	0.28	1.08	0.76	0.62		2.9

Table 5.4.2 Average responses to (a) Q16, (b) Q17 and (c) Q18 respectively left to right for high-rise dwellings.

Q 16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total–	Weighted average
Total	1	1	13	44	124	183	
%	0.55	0.55	7.1	24.04	67.76		
Weight	0.01	0.01	0.21	0.96	3.39		4.6

Q 17 Do you and/or your family support the availability of environmentally friendly practices and technologies? (1 - 'do not support', 5 – 'highly support')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	3	0	13	61	106	183	
%	1.64		7.1	33.33	57.92		
Weight	0.02	0	0.21	1.33	2.9		4.5

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware')

	-1 (Not important)	-2	-3 (Moderately aware)	-4	-5 (Highly important)	Total	Weighted average
Total	23	28	89	27	16	183	
%	12.57	15.3	48.63	14.75	8.74		
Weight	0.13	0.31	1.46	0.59	0.44		2.9

5.5 The influence of geographical location (represented by three selected cities) on attitudes towards household food waste management

Here the comparison of the responses to the individual questions *between the three selected cities* has been assessed.

Q1 What is your postcode?

All together this survey encompasses 21 postcodes across the three selected geographical regions within the Melbourne metropolitan area. Thus 11, 7 and 3 postcodes are from City of Melbourne, City of Yarra and City of Wyndham, respectively.

Q2 What is the best description of your dwelling?

As anticipated, the data presented in Figure 5.5.1 shows high-rise dwellings are more concentrated in the City of Melbourne (76%), semi-detached/town house (or low-rise) in the City of Yarra (76%) and detached house in the City of Wyndham (94%).

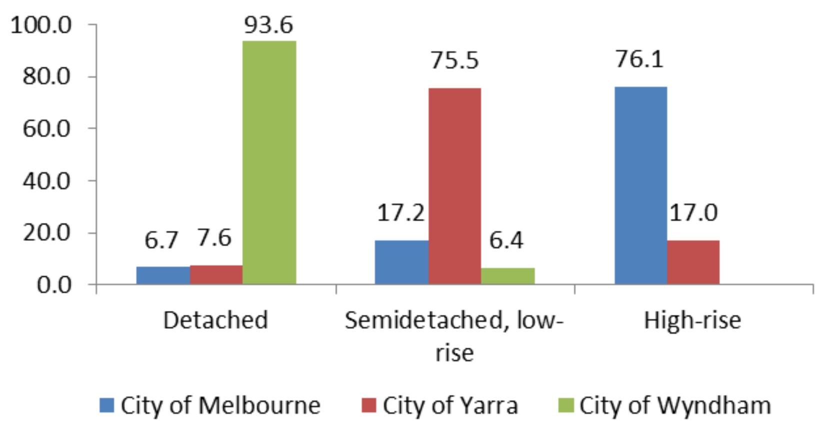


Figure 5.5.1 Dwellings distribution (%) in three geographical regions

The data presented in Figure 5.45 represents a strong validation of our experimental design in so far as the association between dwelling type and geographical location is concerned.

Q3 How many people are in your household?

The average family sizes are 2.31, 2.09 and 3.15 persons respected to City of Melbourne, City of Yarra, and City of Wyndham.

Q4 What is the current status of your dwelling?

The data shown in Figure 5.5.2 is broadly what might be expected and helps to validate the integrity of the survey. For example, it is not surprising that the City of Wyndham and the City of Melbourne have higher mortgage rates that the City of Yarra, considering the demographics revealed elsewhere in this study. Similarly, rental properties are highest in the City of Yarra and significantly lower in the City of Wyndham and the highest home ownership is also in the City of Wyndham.

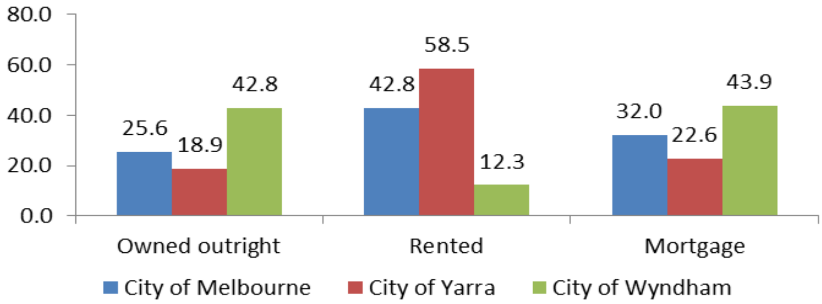


Figure 5.5.2 The status distribution (%) in three geographical regions

Q5 What is your gender?

Interestingly, there is a much higher response rate across all geographic areas by females compared to males, Figure 5.5.3. This might reflect traditional female roles in household matters such as food management.

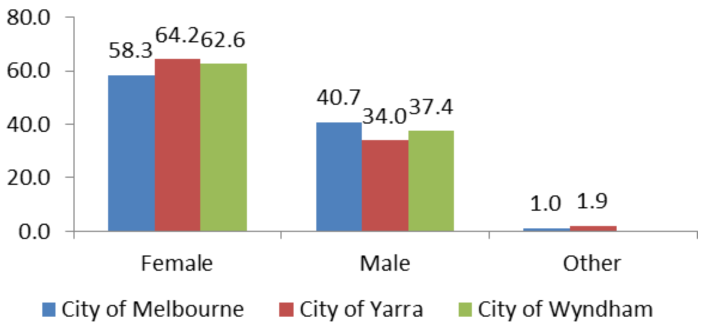


Figure 5.5.3 The gender proportion in three geographical regions

Q6 What is your age range?

Figure 5.5.4 shows the percentage breakdown distribution of age ranges with the three cities. It is not surprising that there is more of an age distribution across the City of Wyndham and a higher proportion of younger residents across the Cities of Melbourne and Yarra.

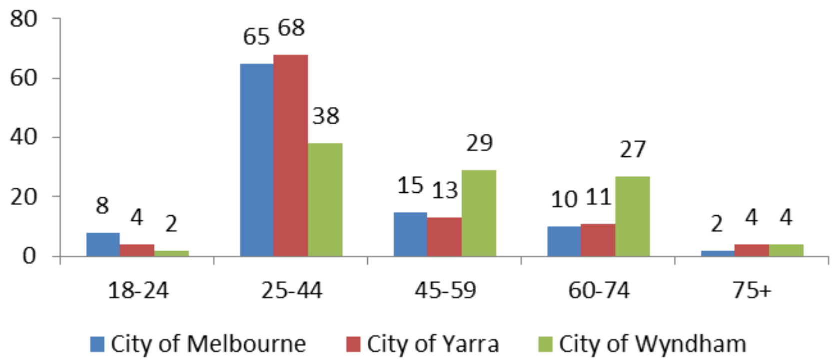


Figure 5.5.4 The age groups of respondents in three geographical regions

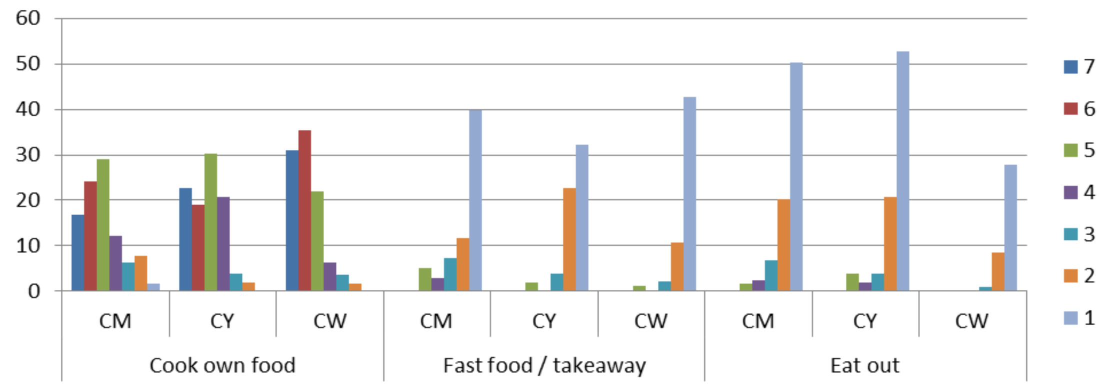
Q7 Please estimate the number of days per week that you. Cook your own food: ____ /per week; Use fast food/takeaway: ____ /per week; Eat out:____ /per week.

Table 5.5.1 and Figure 5.5.5 showed the summary of the responses to the question that outline eating patterns of three cities' residents.

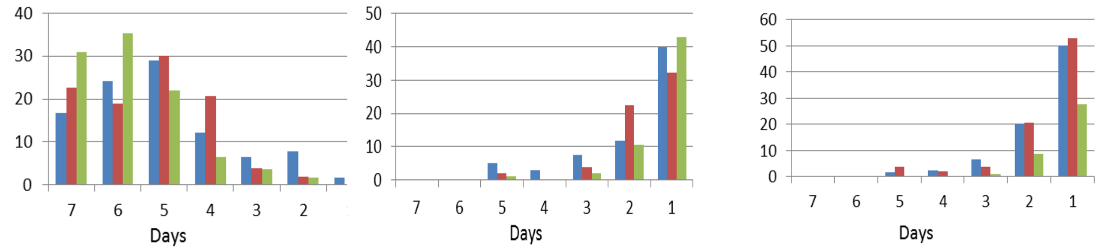
Table 5.5.1 The percentage (%) of responses in different eating pattern (number of days per week) for three geographical locations

Days	Cook own food			Fast food / takeaway			Eat out		
	CM	CY	CW	CM	CY	CW	CM	CY	CW
7	16.8	22.6	31	0.3	0	0	0.3	0	0
6	24.2	18.9	35.3	0	0	0	0	0	0
5	29	30.2	21.9	5.1	1.9	1.1	1.7	3.8	0
4	12.1	20.8	6.4	3	0	0	2.4	1.9	0
3	6.4	3.8	3.7	7.4	3.8	2.1	6.7	3.8	0.9
2	7.7	1.9	1.6	11.8	22.6	10.7	20.2	20.8	8.6
1	1.7	0	0	39.7	32.1	42.8	50.2	52.8	27.8

Note: CM: City of Melbourne; CY: City of Yarra; and CW: City of Wyndham



a. Estimate eating pattern



b. Cook own food c. Fast food / takeaway d. Eat out

Figure 5.5.5 Estimate eating pattern (CM-- City of Melbourne; CY-- City of Yarra and; CW--City of Wyndham)

The data demonstrates that all three geographical regions have similar eating pattern. Comparison between three cities in detail, that the household of City of Wyndham cook their food on home more days and eat out less than other household in other two cities. This may indicate that following the increasing the size of family the family will have more days per week on cooking their food at home and eat out less. Overall the issues of HFW are significant in all three target cities with different reason /condition.

Q8 What is your educational level?

The respondents who live in both Melbourne and Yarra cities have higher percentage of hold a degree than who live in Wyndham city, Figure 5.5.6.

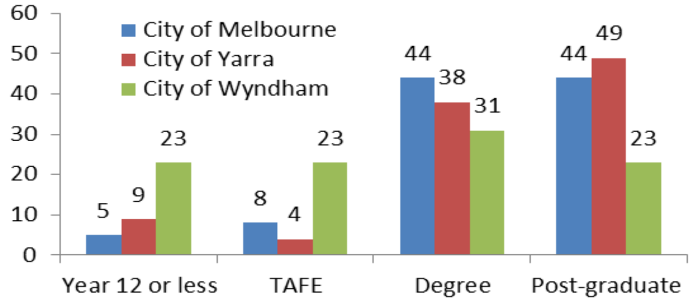


Figure 5.5.6 Education level in three cities

Q9 Please describe your occupation:

There are higher percentage of professional of the respondents in City of Melbourne and City of Yarra, and higher percentage of retired and home duties of the responses in City of Wyndham, Figure 5.5.7. This explains that profession and student will like to live close to centre of Melbourne for convenience of job and study and retired will like to live in out-suburb. This also matches with the education level distribution result in question 8.

Figure 5.5.7 Occupation of the responses in three cities

Q10 How do you currently disposal your food waste?

□ *Council provided garbage bin* □ *Council provided Green bin*

□ *Home composting* □ *Garbage chute*

Home composting and green bin have been used much more by the responses of City of Wyndham than in City of Melbourne and City of Yarra – 40 to 10 and 13; 42 to 26 and 19, Figure 5.5.8. This matches to dwellings type that there is more detached house in City of Wyndham which has more space for home composting facility at their back yard.

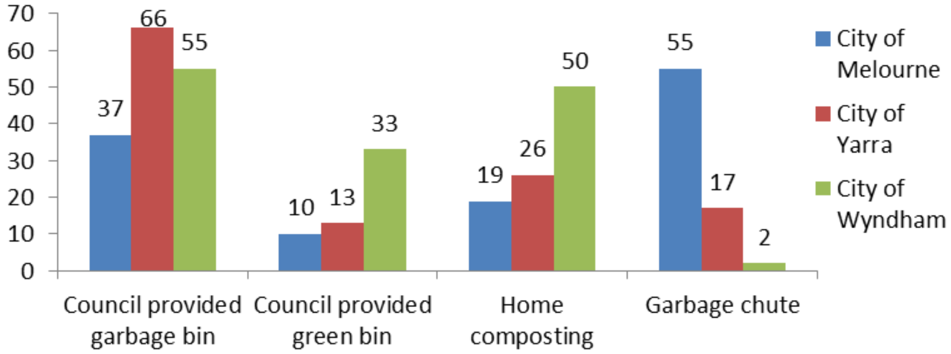


Figure 5.5.8 Current disposal methods of the responses in three cities

Q11 Please provide an estimate of the percentage of food waste in your garbage bin per day? Tick the appropriate box. □ <20% □ 20 – 50% □ >50%

From the Figure 5.5.9 can see that all three cities have similarity percentage of the HFW in their garbage bin per day.

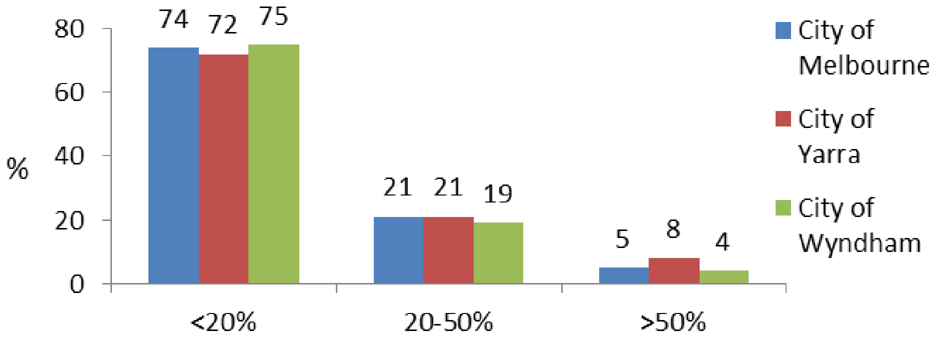


Figure 5.5.9 An estimate of the percentage of HFW in the household of three cities

Q12 Please provide an estimate of the percentage of each of the following components of your food waste.

Fruit and vegetable___%; bread/pasta/other carbohydrates___%; meat/bone/seafood ___%.

The average percentages of three components in three cities are shown in Table 5.5.2.

Table 5.5.2 An estimate of average percentage (%) of three components in the HFW in three cities (CM: City of Melbourne; CY: City of Yarra; and CW: City of Wyndham)

	Fruit / vegetable			Carbohydrate type			Meat / seafood		
	CM	CY	CW	CM	CY	CW	CM	CY	CW
Average percentage	59	64	64	19	16	19	22	20	18

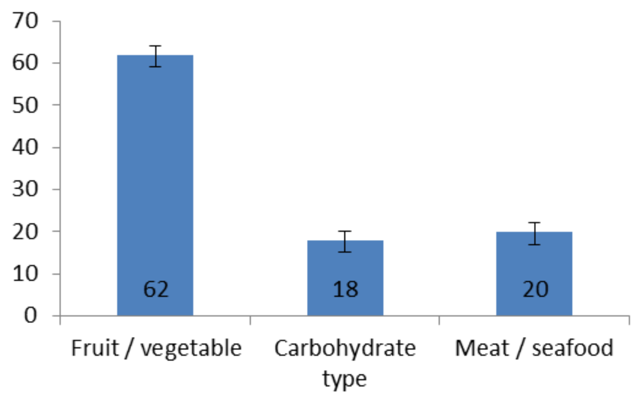


Figure 5.5.10 An estimate of average percentage (%) of three components in the HFW in three cities

The households from both City of Yarra and Wyndham have same the higher percentage (64%) of fruit / vegetable than City of Melbourne (59%). This may be due to the eating pattern that the percentages (93 and 94%) of cooking own food over four days of these two cities are much higher than the percentage (82%) of who live in City of Melbourne (see Table 5.11). And the low percentage in City of Wyndham (56%) may be due to the less wasting while consuming their food. The total average percentage is shown in Figure 5.5.10

Q13 Are you willing to separate your food waste from your other waste?

All three cities have over 90 % the responses on willing to separate HFW from other waste, Figure 5.5.11. The response from City of Melbourne has slightly higher percentage on "no" answer to this question. This may be due to the available space of dwelling for home composting facility or HFW storage and waiting for treatment at home.

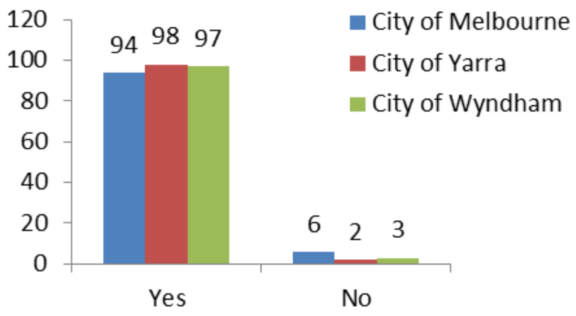


Figure 5.5.11 The percentage (%) on willing to separate the responses' HFW from other waste

Q14 Ideally, what treatment would you prefer for your food waste?

□ *Composting bin in backyard;*

□ *Disposal to garbage bin/chute;*

□ *Treatment at your kitchen sink* - *combined with appropriate technology to process the waste;*

□ *Other (please specify)*

The combination response to this question is shown in Figure 5.512.

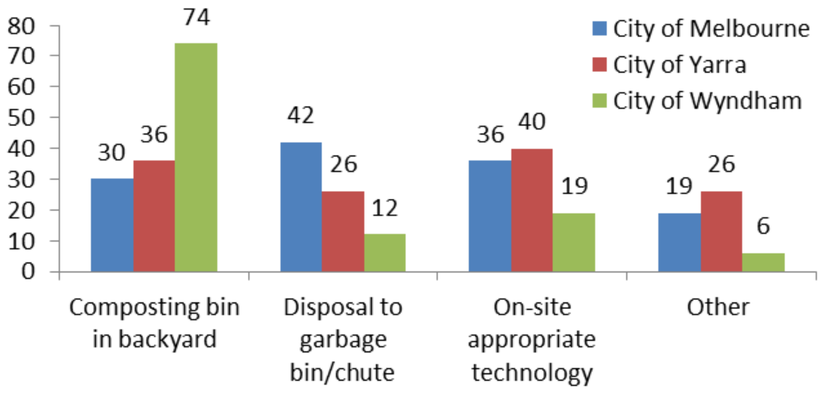


Figure 5.5.12 The prefer treatment for HFW of the responses in three cities

There are near and over double percentage household from cities of Melbourne and Yarra prefer to on-site appropriate technology (36 and 40%) compared to from City of Wyndham (19%). And over double percentage (74%) household from City of Wyndham prefers to composting bin in backyard than other two cities (30 and 36 %) due to the available space of their detached house.

Q15 What is most likely to motivate you to segregate your food waste? Please rank the following from 1 to 6 (1 being the most likely). Council regulation ____; Peer pressure ____; Economic benefit ____; Availability of separating and disposal technology ____; Environmental reasons____; Cleanliness/hygiene____.

The availability of technology has second high score on motivation household to segregate their HFW from other waste after from environmental reason in both centre city (City of Melbourne) and inner-suburb (city of Yarra), and third high score on out-suburb (City of Wyndham), Figure 5.5.13. The result from this question also match the result question 14 that the household who live in cities of Melbourne and Yarra are more prefer to on-site appropriate technology.

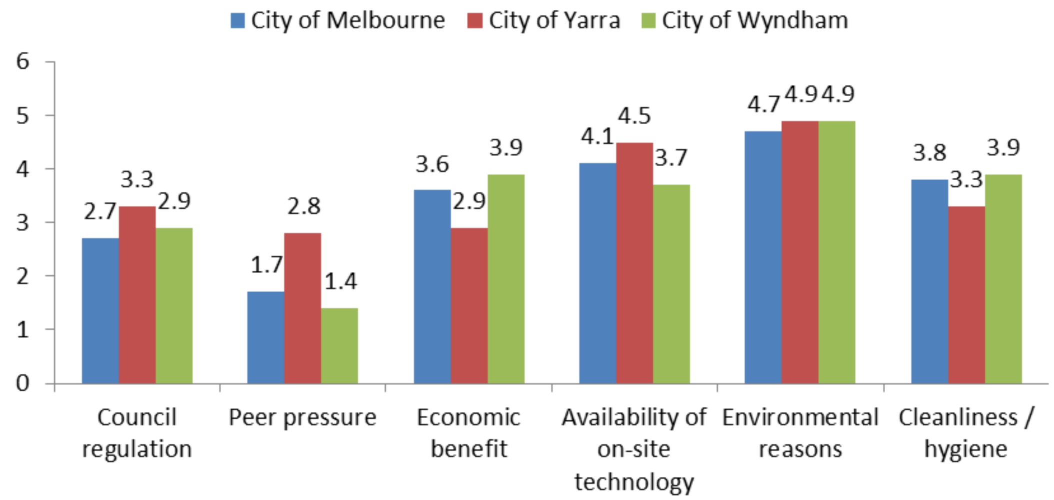


Figure 5.5.13 The score on different motivate on segregating the HFW of responses in three cities

Q16 Do you believe that the day-to-day environmental impact of individuals is important to you and subsequent generations? (1 – 'not important', 5 – 'highly important');

Q17 Do you and/or your family support the availability of environmentally friendly practices and technologies?(1 - 'do not support', 5 – 'highly support'); to

Q18 To what extent are you aware of environmental regulations relating to waste disposal? (1 - 'not at all', 3 – 'moderately aware', 5 – 'highly aware'):

All three cities have similarly scores respected to question 16, question 17 and question 18. Comparing between three cities, the households of City of Yarra has the highest scores respected to question 16 and 17. This may relative to the highest percentage in education level of post-graduation in City of Yarra comparing to other two cities (Figure 5.5.14).

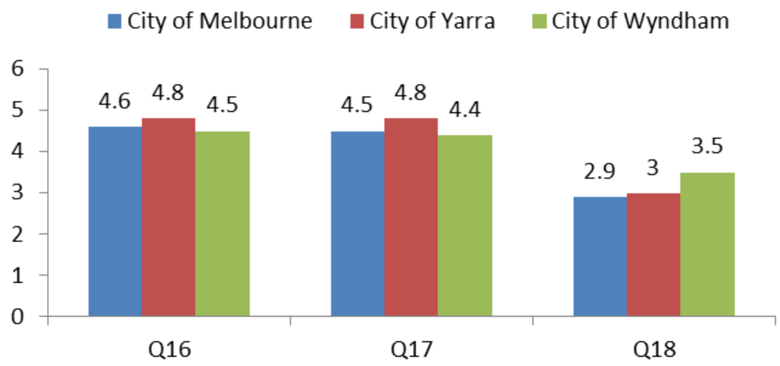


Figure 5.5.14 The attitude toward environmental issues in three cities

Appendices (for Chapter 8)

Table 8.1 VFAs of Run 2

Date	PT	pH	Acetic	Propanoic	Iso-butyric	Butyric	Iso-Valeric	Valeric	Isocaproic	Hexanoic	n-Heptanoic
27/10/2017	T1a	5.7	0.188	0.007	0	0.011					
30/10/2017	T1a	3.78	0.286	0.01	0.006	0.014	0.018	0.022	0.018	0.014	0.016
2/11/2017	T1a	3.35	0.312	0.012	0.02	0.032	0.014	0.012	0	0.008	0.034
6/11/2017	T1a	3.62	0.554	0.016	0.01	0.23	0.042	0.036	0.006	0.018	0.036
8/11/2017	T1a	3.54	0.34	0.008	0.01	0.058	0.024	0.028	0.006	0.012	0.022
14/11/2017	T1a	3.45	0.242	0.008	0.012	0.034	0.022	0.018	0	0.006	0.008
15/11/2017	T1a	3.39	0.238	0.008	0.018	0.032	0.016	0.018	0	0.016	0.008
18/12/2017	T1a	5.06	0.102	0.018	0.006	0.076	0.014	0.012	0.006	0.018	0.012
30/10/2017	T2b	3.9	0.362	0.03	0.006	0.062	0.012	0.012	0.006	0.004	0.008
30/10/2017			0.464	0.074	0.006	0.144	0.006	0.006	0	0.01	0.004
31/10/2017	T2a	3.5	0.422	0.046	0.01	0.08	0.006	0.012	0	0.01	0.014
1/11/2017	T2a	3.19	0.296	0.03	0.01	0.056	0.014	0.012	0	0.014	0.022
2/11/2017	T2a	3.27	0.382	0.032	0.004	0.068	0.006	0.012	0	0.008	0.01
3/11/2017	T2b	3.31	0.632	0.042	0.016	0.084	0.012	0.022	0	0.01	0.008
6/11/2017	T2a	3.44	0.626	0.044	0.008	0.07	0	0.012	0.006	0.01	0.02
8/11/2017	T2a	3.4	0.519	0.023	0.003	0.042	0.003	0	0.003	0.002	0.002
8/11/2017			0.596	0.034	0.006	0.064	0.006	0.006	0	0.01	0.012
14/11/2017	T2a	3.47	0.526	0.032	0.006	0.052	0.006	0.012	0	0.004	0.008
14/11/2017	T2b		0.412	0.02	0.01	0.04	0.006	0.012	0.006	0.004	0.008
15/11/2017	T2a	3.36	1.044	0.056	0.008	0.094	0.012	0.018	0	0.01	0.008
16/11/2017	T2a	3.49	0.495	0.024	0	0.044	0	0.003	0	0.01	0.002

16/11/2017			0.724	0.054	0.008	0.09	0.006	0.018	0.01	0.016	0
28/11/2017	T2a	3.5	0.266	0.022	0.006	0.052	0.006	0.006	0.01	0.006	0
28/11/2017	T2a		0.133	0.011	0.003	0.026	0.003	0.003	0.005	0.003	0
18/12/2017	T2a	38	0.792	0.108	0.056	1.196	0.066	0.096	0.022	0.046	0
18/12/2017	T2a		0.051	0.009	0.003	0.038	0.007	0.006	0.003	0.009	0.006

Appendices (for Chapter 9)

9.1 The gas composition details and total VFAs concentration values for Run 4

Table 9.1.1 The gas composition details (volume mL and percentage) and total VFAs concentration values for PT2 of Run 4

Day / Item	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd	25th	27th	29th	31st	33rd	35th	37th	43rd
CH4	369	1317	1502	484	29	1090	673	266	423	1		368	1079	1086	456		488	884	2202
CO2	183	134	231	107	10	344	276	89	42	5		96	218	319	0		85	225	488
O2	97	68	122	40	2	34	69	113	9	23		24	16	14	4		1	55	19
Balance	1431	1767	1536	610	29	632	282	422	417	101		102	707	341	241		155	276	501
Total gas volume	2080	3280	3390	1240	70	2100	1300	890	890	130		590	2020	1760	700		730	1440	3210
Total VFAs	0.41	0.24		0.36		0.38	0.14	0.33	0.14	0.09	0.39	0.16	1.27	0.18	0.8	0.49	0.21	0.46	
CH4	17.7%	40.2%	44.3%	39.0%	41.4%	51.9%	51.8%	29.9%	47.5%	0.6%		62.3%	53.4%	61.7%	65.1%		66.9%	61.4%	68.6%
CO2	8.8%	4.1%	6.8%	8.6%	14.4%	16.4%	21.2%	10.0%	4.7%	3.6%		16.3%	10.8%	18.1%	0.0%		11.7%	15.6%	15.2%
O2	4.7%	2.1%	3.6%	3.2%	3.2%	1.6%	5.3%	12.7%	1.0%	17.8%		4.1%	0.8%	0.8%	0.5%		0.2%	3.8%	0.6%
Balance	68.8%	53.9%	45.3%	49.2%	41.8%	30.1%	21.7%	47.4%	46.8%	78.0%		17.3%	35.0%	19.4%	34.4%		21.2%	19.2%	15.6%

Table 9.1.2 The gas composition details (volume mL and percentage) and total VFAs concentration values for PT3 of Run 4

Day / Item	9th	11th	13th	15th	17th	19th	21st	23rd	25th	27th	29th	31st	33rd	35th	37th	43rd	60th	69th	73rd
CH4										33.3%	36.5%	64.7%	37.6%	47.4%	55.0%	61.4%	73.0%	82.6%	80.3%
CO2										45.5%	32.2%	49.6%	26.6%	27.7%	29.0%	22.3%	10.7%	8.6%	9.7%
O2										1.8%	0.7%	1.6%	0.3%	0.3%	0.7%	0.3%	1.6%	0.9%	0.2%
Balance										19.3%	30.6%	48.9%	35.4%	24.7%	15.3%	16.0%	14.7%	7.9%	9.8%
CH4									0	200	416	479	587	711	1040	1560	3168	3734	3674
CO2									0	273	367	367	416	416	548	566	464	389	444
O2									0	11	8	12	5	5	13	8	69	41	9
Balance									0	116	349	362	552	371	289	406	639	356	448
Total volume									0	600	1140	740	1560	1500	1890	2540	4340	4520	4575
Total VFAs	0.24		0.17	0.18	0.22	0.68	0.14	0.33	0.20	0.00	0.15	0.50	0.33	0.15	0.30				

9.2 The gas composition details and Total VFAs concentration values for Run 5

Table 9.2.1 The gas composition details (volume mL and percentage) and total VFAs concentration values for PT2 of Run 5

Item \ Day	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st
CH4	154	134	371	2198	1229	935	510	38	39	0
CO2	31	557	502	427	223	293	44	12	18	0
O2	135	675	610	158	28	47	56	285	96	42
Balance	702	1024	2422	2017	150	225	500	1165	427	168
Total volume	1020	2390	3905	4800	1630	1500	1110	1500	580	210
Total VFAs	0.31		0.16	0.18	0.18	0.15	0.17	0.15	0.1	0.15
CH4	15.1%	5.6%	9.5%	45.8%	75.4%	62.3%	45.9%	2.5%	6.7%	0.0%
CO2	3.0%	23.3%	12.9%	8.9%	13.7%	19.5%	4.0%	0.8%	3.1%	0.0%
O2	13.2%	28.2%	15.6%	3.3%	1.7%	3.1%	5.0%	19.0%	16.6%	20.0%
Balance	68.8%	42.8%	62.0%	42.0%	9.2%	15.0%	45.0%	77.7%	73.6%	80.0%

Item \ Day	23rd	27th	29th	33rd	35th	39th	47th	66th	71st
CH4	10	225	82	684	1	1047	3972	4938	5046
CO2	11	191	48	436	1	382	516	606	618
O2	10	6	18	16	187	34	216	0	0
Balance	49	1068	327	1504	711	1617	1296	456	336
Total volume	80	1490	475	2640	900	3080	6000	6000	6000
Total VFAs	0.12	0.15	0.11	0.24	0.09				
CH4	12.5%	15.1%	17.3%	25.9%	0.1%	34.0%	66.2%	82.3%	84.1%
CO2	13.8%	12.8%	10.1%	16.5%	0.1%	12.4%	8.6%	10.1%	10.3%
O2	12.5%	0.4%	3.8%	0.6%	20.8%	1.1%	3.6%	0.0%	0.0%
Balance	61.3%	71.7%	68.8%	57.0%	79.0%	52.5%	21.6%	7.6%	5.6%

Table 9.2.1 The gas composition details (volume mL and percentage) and total VFAs concentration values for PT3 of Run 5

Day / Item	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st
CH4					27	76	365	197	185	555
CO2					179	20	617	303	245	606
O2					32	4	10	76	0	6
Balance					182	100	1613	1269	765	993
Total volume					420	200	2605	1845	1195	2160
Total VFAs				0.18	0.15	0.06	0.15	0.15	0.14	0.18
CH4					6.4%	38.0%	14.0%	10.7%	15.5%	25.7%
CO2					42.6%	10.0%	23.7%	16.4%	20.5%	28.1%
O2					7.6%	2.0%	0.4%	4.1%	0.0%	0.3%
Balance					43.3%	50.0%	61.9%	68.8%	64.0%	46.0%

Day / Item	23rd	27th	29th	33rd	35th	39th	47th	66th	71st
CH4					27	76	365	197	185
CO2					179	20	617	303	245
O2					32	4	10	76	0
Balance					182	100	1613	1269	765
Total volume					420	200	2605	1845	1195
Total VFAs				0.18	0.15	0.06	0.15	0.15	0.14
CH4					6.4%	38.0%	14.0%	10.7%	15.5%
CO2					42.6%	10.0%	23.7%	16.4%	20.5%
O2					7.6%	2.0%	0.4%	4.1%	0.0%
Balance					43.3%	50.0%	61.9%	68.8%	64.0%

9.3 The gas composition details and total VFAs concentration values for Reference unit C

Table 9.3.1 The gas composition details (volume mL and percentage) and total VFAs concentration values for C1

Day / Item	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd	25th	27th	29rd	31th	33th	35th	37th
CH4	43	125	20	4	6			9	190	386	615	79	712	531	441	157	238	54
CO2	161	826	229	689	330			13	1068	1045	943	67	880	764	883	237	312	105
O2	24	32	19	15	7			5	20	26	20	3	28	33	16	22	14	15
Balance	378	258	137	283	137			13	233	158	67	18	105	152	20	47	0	35
Total volume	605	1240	405	990	480	0	0	40	1510	1615	1645	168	1725	1480	1360	463	565	210
Total VFAs	1.2		6.3		4.7	2.7	3.5	3.4	2.1	3.0	4.3	7.2	5.8	2.2	2.5	1.3	2.7	2.7
CH4	7.1%	10.1%	4.9%	0.4%	1.3%	0.0%	0.0%	23.6%	12.6%	23.9%	37.4%	47.1%	41.3%	35.9%	32.4%	33.9%	42.2%	25.7%
CO2	26.6%	66.6%	56.6%	69.6%	68.8%			31.5%	70.7%	64.7%	57.3%	40.1%	51.0%	51.6%	64.9%	51.2%	55.3%	50.2%
O2	3.9%	2.6%	4.7%	1.5%	1.5%			13.6%	1.3%	1.6%	1.2%	1.9%	1.6%	2.2%	1.2%	4.7%	2.5%	7.2%
Balance	62.5%	20.8%	33.8%	28.6%	28.5%	0.0%	0.0%	31.3%	15.4%	9.8%	4.1%	10.9%	6.1%	10.3%	1.5%	10.2%	0.0%	16.9%

Table 9.3.2 The gas composition details (volume mL and percentage) and total VFAs concentration values for C2

Day / Item	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd	25th	27th	29rd	31th	33th	35th	37th
CH4	41	256	1	1	27			6	450	460	282	385	257	356	159	37	0	0
CO2	167	1015	133	99	2			15	55	34	24	34	29	38	15	13	0	0
O2	23	35	34	5	10			0	4	3	58	8	3	22	13	3	0	0
Balance	384	234	37	65	42			59	584	932	456	928	700	954	383	62	0	0
Total volume	615	1540	205	170	80	0	0	80	1093	1430	820	1355	988	1370	570	115	0	0
Total VFAs	1.5		1.5		1.0	2.8	3.1	1.1	1.0	0.4	1.5	4.2	3.7	2.3	2.2	2.1	1.4	2.2
CH4	6.7%	16.6%	0.6%	0.4%	33.2%	0.0%	0.0%	7.8%	41.2%	32.2%	34.4%	28.4%	26.0%	26.0%	27.9%	32.4%	0.0%	0.0%
CO2	27.1%	65.9%	64.8%	58.0%	2.0%			18.2%	5.0%	2.4%	2.9%	2.5%	2.9%	2.8%	2.6%	10.9%	0.0%	0.0%
O2	3.7%	2.3%	16.4%	3.1%	12.9%			0.1%	0.4%	0.2%	7.1%	0.6%	0.3%	1.6%	2.3%	2.7%	0.0%	0.0%
Balance	62.5%	15.2%	18.2%	38.5%	51.9%	0.0%	0.0%	73.9%	53.4%	65.2%	55.6%	68.5%	70.8%	69.6%	67.2%	54.0%	0.0%	0.0%

Table 9.3.3 The gas composition details (volume mL and percentage) and total VFAs concentration values for C3

Day / Item	3rd	5th	7th	9th	11th	13th	15th	17th	19th	21st	23rd	25th	27th	29rd	31th	33th	35th	37th
CH4	152	243	73	238	67			48	88	366	345	370	336	317	299	258	138	62
CO2	637	948	373	123	45			7	66	434	422	498	505	396	340	258	96	11
O2	59	69	31	143	13			10	27	22	22	24	51	23	22	13	10	9
Balance	637	242	133	377	60			135	165	71	80	73	52	114	128	89	46	33
Total volume	1520	1503	610	880	185	0	0	200	347	893	868	965	943	850	790	618	290	115
Total VFAs	1.5		2.9		4.5	6.1	0.5	8.7	1.9	2.9	3.5	10.9	9.7	4.4	4.2	6.2	7.5	10.1
CH4	10.0%	16.2%	12.0%	27.0%	36.4%	0.0%	0.0%	23.8%	25.5%	41.0%	39.7%	38.3%	35.6%	37.3%	37.9%	41.8%	47.6%	53.9%
CO2	41.9%	63.1%	61.2%	14.0%	24.3%			3.6%	19.0%	48.6%	48.6%	51.6%	53.5%	46.6%	43.1%	41.7%	33.0%	9.6%
O2	3.9%	4.6%	5.0%	16.2%	6.9%			5.2%	7.9%	2.5%	2.5%	2.5%	5.4%	2.7%	2.8%	2.1%	3.6%	7.6%
Balance	44.2%	16.1%	21.8%	42.8%	32.4%	100.0%	100.0%	67.4%	47.6%	7.9%	9.2%	7.6%	5.5%	13.4%	16.2%	14.4%	15.8%	28.9%